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**A SYSTEMS APPROACH TO
ASSET MANAGEMENT
IN THE HYDRO-ELECTRIC SECTOR**

By

E. J. Baker-Langman

A thesis submitted to the University of Bristol in accordance with the requirements for the degree of Doctor of Philosophy in the Faculty of Engineering, Department of Civil Engineering.

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ABSTRACT

The premise for this thesis is that successful management of physical assets must consider not only the infrastructure, but also the wider system within which it is located. Only through 'systems thinking' can the performance of a complex asset be managed to meet the demand being placed on it by its stakeholders, which may include customers; shareholders; staff; regulators and suppliers. In order to balance the competing demands of the various stakeholders, an organisation must be able to link the work that is carried out in maintaining, improving and replacing assets, to the service demands. This can only be done through understanding the processes occurring within and between the assets being managed.

Current best practice in Asset Management revolves around principles of risk management, lifecycle planning and prioritisation. This requires a good understanding of interactions within the system, which could be gained from a process-based view of performance. A review of existing process models reveals a need for a generic methodology for building process models that could support improved Asset Management for organisations whose main asset base includes complex infrastructure elements. This should ultimately result in improved condition monitoring, management and performance of existing assets, and point out any need for further investment in new assets or data collection.

An enhanced Asset Management methodology is developed through the course of this research and is demonstrated on a simplified case study based on part of the business of Scottish and Southern Energy plc. The study reveals the importance of process modelling in allowing an organisation to overcome the dangers of silo-organisation, as represented in the traditional organigram. The enhanced methodology encourages greater communication along cross-functional lines rather than through a department-by-department approach and could therefore support the implementation of quality systems such as ISO 9001.

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There are so many people who have supported me during this research that I apologise if I have forgotten to name any individuals here. First, of course, I must thank my supervisor, Professor Colin Taylor, and my other friends and colleagues at Bristol for their support and advice. In particular, I would like to thank the members of the CMAM research team, Dr Jim Hall, Dr John Davis and Richard Dawson; as well as Jason Le Masurier, Jonathan Evans, Jorge Tiago Pinto, Lynne Walker, Aime Thomas-Harrison, Gordon Barr and, of course, the Porters who have helped me keep research in perspective.

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As always, my family have been incredibly supportive. Thanks for everything Bakers, Langmans, Sawkinses, Bryants and Netherclifts! I am especially grateful to Phil and Kate for keeping me going through the last, long months of writing up.

DECLARATION

I declare that the work in this dissertation was carried out in accordance with the Regulations of the University of Bristol under the supervision of Prof C.A. Taylor. The work is original except where indicated by special reference in the text and no part of the dissertation has been submitted for any other degree.

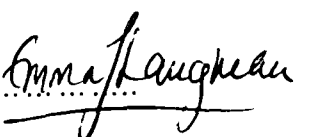
Any views expressed in the dissertation are those of the author and in no way represent those of the University of Bristol. This dissertation has not been presented to any other University for examination, either in the United Kingdom or overseas.

The following papers are based on the work described in this thesis:

1. Baker-Langman, E.J., Hall, J.W., Taylor, C.A., and Davis, J.P. (2002)*, “Evidence-based Decision Support Tool for Management of Complex Infrastructure Systems”, *DMinUCE Conference Proceedings (Electronic)*, DMinUCE, London, November.
2. Hall, J.W., Davis, J.P., Taylor, C.A., Durgaprasad, J., Dawson, R. and Baker, E.J. (2000)* “Performance-Based Asset Management for Complex Infrastructure Systems” *ICOSSAR*. London.
3. Hall, J.W., Le Masurier, J.W., Baker, E.J., Davis, J.P., Taylor, C.A., (2002a)*, “A decision-support methodology for performance-based infrastructure management” *ASCE Journal of Infrastructure Systems*, pp. 37-48.
4. Hall, J.W., Le Masurier, J.W., Baker, E.J., Davis, J.P., Taylor, C.A. (2002b)*, “Multi-attribute performance monitoring for reservoir systems” *Reservoirs in a changing world – Proceedings of the 12th conference of the BDS held at Trinity College*, (ed. Tedd, P.), pp. 534-550, Dublin, September.
5. Hall, J.W., Le Masurier, J.W., Baker-Langman, E.J., Davis, J.P., Taylor C.A., (2003)*, “A Decision-Support Methodology for Performance-based Asset Management”, *Civil Engineering and Environmental Systems*.
6. Langman and De Rosa (2003) ⁺, “Making defensible decisions in the face of uncertainty”, *Proceedings of the International Conference on Advance in Water Supply Management*, Balkema Publishers, pp.375-384, London, September.

7. Langman, E.J. and Brown, K. (2003)⁺, “The 10-year Plan for Roads and Transport – Measuring the difference”, *proceedings of APSE Conference*, Belfast, September.
8. Langman, E.J., Leicester, M. and Roberts, C.M. (2003)⁺, “Achieving Better Results Through Open Performance Management”, *Proceedings of the ERA Conference on Engineering Asset Management*, pp. 7.1-7.13, London, October.
9. Langman, E.J. (2003)⁺, “Making Defensible Decisions in the Management of Dam Systems”, one of five papers entered into the British Dam Society’s Young Engineer competition, accepted for future publication in *Dams and Reservoirs*.

Note: Items marked with * relate to work carried out as part of the CMAM research project. Those marked with ⁺ relate to industrial applications of the work described in this thesis. The author has used her maiden name, Baker and married name, Langman as appropriate.

Signed: 

Date: 11/02/04

“After 2,400 years of immense complacency and self-satisfaction with our traditional thinking methods it is time to appreciate that they are not sufficient. ”

New Thinking for the New Millennium, Edward de Bono

“Facts which at first seem improbable will, even in scant explanation, drop the cloak which has hidden them and stand forth in naked and simple beauty.”

Galileo Galilei

“Personal transformation requires deep understanding of the theory of a system. It requires acceptance of the philosophy of win-win in negotiation between people, between countries, between companies, between supplier and customer, between union and management. This personal transformation is discontinuous, sudden. Once transformed, one may thereupon work toward transformation of his own organization.”

W. Edwards Deming

DEDICATION

To my family: past, present and future.

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NOTATION & ACRONYMS

| | |
|--------------------|--|
| ALARP | As Low As Reasonably Practicable |
| AM | Asset Management |
| APT | Asset Performance Toolkit |
| BEM | Business Excellence Model |
| BSi | British Standards Institute |
| BVPI | Best Value Performance Indicator |
| CASE | Computer Aided Software Engineering |
| CMAM | Condition Monitoring and Asset Management (Bristol research project) |
| DSS | Decision Support System |
| DST | Decision Support Tool |
| EFQM | European Foundation for Quality Management |
| ETA | Event Tree Analysis |
| FAST | Functional Analysis Systems Technique |
| FEH | Flood Estimation Handbook |
| FMEA/ FMECA | Failure Modes and Effects (Criticality) Analysis |
| FSR | Flood Studies Report |
| FTA | Fault Tree Analysis |
| HAZAN | HAZard ANalysis |
| HAZOP | HAZard and OPerability study |
| HPT | High Performance Team |
| HSE | Health and Safety Executive |
| IAM | Institute of Asset Management |
| IEE | Institute of Electrical Engineers |
| ICOLD | International Committee on Large Dams |
| IDEF | International DEFinition (Modelling methods) |
| IIMM | International Infrastructure Management Manual |
| IPT | Interval Probability Theory |
| KPI | Key Performance Indicator |
| MTBF | Mean Time Between Failures |
| ODPM | Office of the Deputy Prime Minister |
| PAR | People At Risk |
| PAS | Publicly Available Specification |
| PC | Personal Computer |
| PDA | Personal Digital Assistant |
| PDSA | Plan-Do-Study-Act (Deming/Shewhart Cycle) |

| | |
|------------|-----------------------------------|
| Pf | Probability of Failure |
| PI | Performance Indicator |
| PMF | Probable Maximum Flood |
| PMT | Performance Management Team |
| RCM | Reliability-Centred Maintenance |
| RGa | Repertory Grid Analysis |
| RP | Risk Priority |
| SBU | Strategic Business Unit |
| SSE | Scottish and Southern Energy plc. |
| SSM | Soft Systems Methodology |
| UML | The Unified Modelling Language |
| UP | The Unified Process |
| VSM | Viable Systems Model |
| XML | eXtensible Markup Language |

GLOSSARY

| | |
|--|--|
| Acceptable Risk | A risk which, for the purposes of life or work, everyone who might be impacted is prepared to accept assuming no changes in risk control mechanisms [HSE, 2001]. |
| As Low As Reasonably Practicable (ALARP) Principle | The principle that there is an area of tolerable risk between intolerable and negligible risk and that this risk must be reduced until “the reduction is impracticable or its cost is grossly disproportionate to the improvement gained” [HSE, 2001]. |
| Asset | A physical component of a facility which has value, enables services to be provided and has an economic life of greater than 12 months [IAM, 2002]. |
| BCIOD+R | Six KPIs: managing Business, delighting Customers, Integrating processes, Operating assets, Delivering assets + Regulating [Blockley & Godfrey 2000]. |
| Business Excellence Model (BEM) | A non-prescriptive framework which recognises there are many approaches to achieving sustainable excellence [Bicheno 2002]. |
| Decision Support System (DSS) | Computer based information systems that combine models and data in an attempt to solve non-structured problems with extensive user involvement [Turban and Alonson, 1998]. |
| Decision Support Tool (DST) | Software elements (such as languages) that facilitate the development of a DSS, or a DSS generator [Turban and Alonson, 1998]. |
| Dynamic Asset | An asset with some moving parts [IAM, 2002] |
| Elicitation | The act of extracting knowledge, generally automatically from non-human sources; machine learning [Turban and Alonson, 1998]. |
| Executive Information System | Computerised system that is specifically designed to support executive work [Turban and Alonson, 1998]. |
| Factor of Safety | The ratio of system resistance to the peak design loads |

| | |
|--|--|
| | [McDonald <i>et al</i> , 2000]. |
| Glocal | Effects and issues that are experienced locally but are created and must be managed globally [Beck, 2001]. |
| Infrastructure assets | Stationary systems (or networks) that serve defined communities where the system as a whole is intended to be maintained indefinitely to a specified level of service by the continuing replacement and refurbishment of its components [IAM, 2002]. |
| Key Performance Indicator (KPI) | Specific measures of the critical success factors in an Executive Information System [Turban and Alonson, 1998]. |
| Passive Asset | An asset with no moving parts [IAM, 2002]. |
| People at Risk | The number of people whose lives are at risk from the consequences of a particular event, such as a dam breach. |
| Performance Indicator (PI) | A parameter or variable that describes a process [Blockley & Godfrey 2000]. |
| Performance Management Team (PMT) | A group within a particular local authority that manage the performance indicators (including BVPIs) for that authority. |
| Quality | 'the totality of features and characteristics of a product or service which bear on its ability to satisfy a given need' [BS4778] |
| Repertory Grid Analysis (RGA) | A tool used by psychologists to represent a persons view of a problem in terms of its elements and constructs [Turban and Alonson, 1998]. |
| Strategic Business Unit (SBU) | There are usually several SBU's in a division of a company (e.g. innovation, operations and modelling) [Kaplan & Norton]. |
| Tablet PC | A handheld computer that is about half the size of a conventional laptop computer |
| Viable Systems Model (VSM) | Beer's organisational model [Flood, 1999] |

1.1 Background

The aim of the research described in this thesis and carried out at the University of Bristol as part of the EPSRC-funded Condition Monitoring and Asset Management (CMAM) project was stated as:

“to develop new decision support techniques to improve the safety and economic performance of complex civil engineering infrastructure systems”

(Hall *et al*, 2001)

The complex civil engineering infrastructure systems considered during the course of the whole CMAM project were those where the decisions to be made were commercially important or safety critical. Hence, dams, flood and coastal defences, and engineered and natural slopes were all considered in CMAM. This thesis focuses on dams, but the ideas and methodology are generic and can be applied to any asset.

These three types of infrastructure have five characteristics in common (Hall *et al*, 2001):

- (i) The physical failure mechanisms are complex and site-specific;
- (ii) The structural behaviour is spatially varied: this is often associated with natural variability in the loading regime (wind, wave, rainfall, seismic) and geotechnical conditions;
- (iii) Monitoring information tends to be scarce and expensive (or impossible) to obtain;
- (iv) Expert judgement is a major element of condition monitoring (due to the scarcity of quantitative information and the complexity of the physical processes); and
- (v) Condition assessments are characterised by uncertainty, which can result in monitoring and remediation resources being misdirected.

Just as it is possible to point out similarities between the three types of assets considered, their main reason for existence results in their particular management focus:

- (i) Some dams and all coastal and flood defences are in existence to protect life and property. This means that in order to consider their value in monetary terms, the financial value of that which they protect must be considered;

- (ii) Privately-owned dams belonging to hydro-electric schemes exist primarily to produce money for the company that operates them, although other benefits (tourism etc.) may result; and
- (iii) Engineered slopes may exist as an economical method for storing waste material or to allow for the construction of roads and railways. The second case will result (indirectly) in money being made, since the cars or trains that will use the new transport infrastructure will result in either direct income (through tolls) or increased income for the nation. Where the slopes have been built to store waste materials or where slopes are naturally occurring, it is harder to see where money can be made, although it is possible to see how failure to stabilise the slopes could result in loss of money.

In the three sectors studied as part of the CMAM project it is clear that the consequences could be serious if the wrong management decision is taken.

1. In the dam sector, a decision or lack of decision that resulted in even a small-scale accident with no serious injuries to human beings could affect the industry as a whole. This is particularly true in western countries where dams fail very infrequently. In the UK there has not been a life lost due to dam failure since 1925 (Charles, 2002a). This means that the perception of the general public is that dams are safe, inanimate objects. Even a minor incident could result in fears regarding the safety of other dams, which could easily lead to new ‘knee-jerk’ legislation and increased expenditure for dam owners. The issue is that there is not, and may never be, an accepted method for ascertaining the safety of a dam in quantitative terms (Hartford, 2000; Hartford and Stewart, 2002).
2. The failure of coastal and flood defences can result in the loss of hundreds or even thousands of lives and millions of pounds worth of property. The UK floods of the autumn of the year 2000 are estimated to have resulted in over £1bn worth of property damage (Crossley, 2001). In addition, since such failures can be very large scale and attract a great deal of publicity, they can result in political difficulties for the government of the country where the disaster occurs.
3. Failure of slopes, both natural and engineered, can result directly in death or other losses. Perhaps the most famous of these to have occurred in the UK is the Aberfan Disaster, which took 144 lives in 1966 (McLean and Johnes, 2000). Even where death does not result, the cost of slope collapse can be great. for example, during persistent wet weather in the UK during the autumn of 2000, train services were repeatedly disrupted by slopes falling onto the track. This resulted in a loss of

consumer confidence in journey time reliability with the resultant loss of earnings, as well as costs due to repairs and compensation to passengers and train operators. On New Year's Day, 2003, a landslide caused a train to derail, further damaging customer confidence in the UK's rail network.

The examples given above have been deliberately confined to the UK. Clearly, as the eminent sociologist Beck postulates (2001) the world must now concern itself with "glocal" issues, those that are experienced locally but do not respect national or regional boundaries (such as climate issues, pollution, fire, etc). While this thesis restricts itself to the discussion of the application of systems thinking to complex physical infrastructure assets, the ideas explored could be utilised in a wider socio-economic context.

1.2 Objectives of the Thesis

This work has five key objectives. These are:

1. To identify the current challenges faced by infrastructure-intensive organisations and evaluate current Condition Monitoring and Asset Management methods;
2. To identify and evaluate possible methods for modelling the performance of a complex infrastructure system and discuss critically some of the fundamental issues underlying current modelling ideas and techniques;
3. To identify and discuss critically the benefits and constraints associated with existing systems models, and to select the preferred model type for this research;
4. To produce a robust generic methodology for modelling a complex infrastructure system based on the outcome of objective three, to carry out a case study of a major asset belonging to Scottish and Southern Energy plc, and to test the outcomes of objectives one through three; and
5. To evaluate the usefulness of the model methodology and comment on whether the tools chosen to construct the model (through objectives one to four) are viable or could be modified in some way, and to provide generic suggestions for using this work to model and thus improve other complex asset management systems.

1.3 Core Goal

The main goal of this research has been to determine a robust method for building process models that describe an organisation at various levels. A case study of the methodology should be developed which allows the novel ideas of the CMAM group at the University of Bristol to be tested in a 'real-life' application.

1.4 Layout

The contents of the remaining chapters of this thesis are outlined below.

Chapter Two comprises an overview of the challenges facing those professionals involved with the Condition Monitoring and Asset Management (CMAM) of complex infrastructures. This thesis presents a case study of a hydro-electric dam system, loosely modelled on the Scottish and Southern Energy assets in Scotland. This chapter tackles the following questions:

- (i) What are the CMAM challenges faced by the hydro-electric/ dam sector?
- (ii) What is the best CMAM practice in this field?, and
- (iii) What are the current (and best) CMAM methods in other industries?
- (iv) Could any of these methods be transferred in whole or part to the hydro-electric dam sector?

Chapter Three focuses on the way in which the research has been carried out. It describes how the author selected the problem domain and employed modern elicitation methods to develop the work.

Chapter Four is an overview of current best practice in the dam sector. This considers issues including organisational structure, management of knowledge, information and data, and the consideration of specific domain-related issues such as safety, efficiency and managing risk.

Chapter Five provides an overview of best asset management practice in other sectors and describes how this is complemented by Risk Management, Quality Management and Value Management. The chapter demonstrates how all these facets of management depend on a thorough understanding of the system being managed.

Chapter Six provides an introduction to systemic thinking from ancient times until the modern day. A synthesis of a number of existing systems models is presented with a critique of each. The chapter leads to the conclusion that a simple generic modelling methodology should be developed to support Asset Management of complex infrastructure systems.

Chapter Seven recounts some of the main findings that have come about as part of the CMAM work conducted at Bristol University between 1999 and 2002. It describes the advances that this work offers over existing techniques used in the CMAM field and within

the hydro-electric/ dam sector. The CMAM/Perimeta tool that has been developed through that research is described.

The centre of the thesis is *Chapter Eight*. It explains how existing CMAM practice can be spliced with systems and process modelling techniques developed in other sectors (particularly the computer industry and industrial management) and then developed through linkage to the latest thinking regarding CMAM from the University of Bristol, to produce a robust method for modelling and, ultimately, resolving CMAM issues relating to complex engineering infrastructure systems.

Chapter Nine comprises the final case study developed for a simple hydro-electric dam system (extracted from the Scottish and Southern Energy company system). It focuses on a generic reservoir system, so that all aspects of the system, and all levels of the hierarchy, from top management issues down to small components, can be considered. The case study also considers the interaction between the physical system and the wider stakeholder group (including society in general). The chapter finishes with a review of whether or not the model has met its goal of assisting in Condition Monitoring and supporting Asset Management decisions and whether or not it could be extended to provide a working model for a company such as Scottish and Southern Energy plc.

The final chapter, *Chapter 10* contains the Conclusions and Recommendations arising from the work and outlines how the methodology might be adapted by the hydro-electric/ dam sector and has been applied in other sectors. A short critique of the usefulness of the software tool that has been developed in Bristol is included in this section. The chapter also considers whether a real-time version of the model could be developed to assist with instantaneous day-to-day decision-making. A short description of the author's success in applying the methodology and tool, now known as Perimeta, in industry, is given to conclude the thesis.

Appendix A contains a list of existing tools that have been developed specifically for building process models. This list is by no means exhaustive, but illustrates the number of tools that are currently available. *Appendix B* introduces the key aspects of the UML (Unified Modelling Language) that are exploited by the proposed methodology. *Appendix C* comprises a number of tables to provide the reader with additional details of the case study described in Chapter 9. Finally, *Appendix D* provides a description of the Performance Improvement Cycle; the service that FaberMaunsell now offer clients, which has followed on from the research described in this thesis.

The CMAM Problem

2.1 Introduction

As part of the Condition Monitoring and Asset Management (CMAM) project carried out at the University of Bristol, representatives from eight collaborating organisations from the public and private sectors formed a consultative committee. During a workshop session, the generic CMAM problems facing industry were identified along with an indication of the principal sources and types of uncertainty being handled by the organisations.

It was clear that there were two main areas of concern for managers of complex assets. These were:

- (i) Accurately assessing the current condition of assets; and
- (ii) Making asset management decisions.

The two postgraduate students involved in the CMAM project, the author and Richard Dawson, agreed to carry out innovative research into each of these areas. Mr Dawson embarked on a case study with the Environment Agency, which was aimed at discovering new and more effective ways of carrying out condition characterisation assessments on flood and coastal defence assets.

The author determined to focus on the way in which managers use available evidence to inform asset management decisions. It soon became clear that what the managers lacked was a cohesive and robust overview of the system for which they were responsible. Following research into the Condition Monitoring and Asset Management challenges faced by Scottish and Southern Energy plc, a case study was carried out to identify and test out innovative methodologies for their resolution.

2.2 CMAM Challenges in the Hydro-Electric Industry

Since the beginning of time, man has been eager to harness natural resources to provide assistance with the tasks needed to sustain life. With the increasing debate about global warming and the resulting increases in flooding, this demand for use of renewable resources is set to remain a focus of the world's attention.

Water has been harnessed in many ways, from simply being used for drinking, through assisting in the task of sieving for gold, or turning a water mill to make flour, to its ability to provide electricity. The technologies used for this latter feat are varied. Electricity can be generated from ‘run of the river’ schemes, which make use of the water as it flows through a valley. Alternatively, water may be stored behind a dam within a valley to provide the necessary head required for the generation of electricity from a turbine.

2.2.1 Political and Social Context

An interested observer attending a conference of dam engineers who are responsible for deciding the management strategy for their assets will find that conversation does not simply extend to the discussion of the complex technical issues associated with the hydro-electric dam systems; rather, there will be a great deal of time devoted to debating the future policy plans of the Government. This reflects the important role that policy plays in allowing those generating electricity in this way to meet their principal goal – that of making money. Thus, any model of a physical asset system in this field must take into account the political environment of the day.

It is important to realise that the challenges facing the Hydro-Electricity industry in the western world are not identical to those taken on by those in charge of building and maintaining schemes in the developing world. Without doubt the political climate has a major effect on the way in which hydro-electricity systems are built and managed. An entire thesis could be written by an economics, geography or politics student regarding the complex challenges facing people in the developing world and the effect of this on investment in hydro-electricity production. In poorer countries, factors such as gaining and retaining funding from organisations such as the World Bank are critical to the development and management of hydro-electric dam schemes. The political and economic background within which a scheme is located will result in certain demands being placed on the managers of that asset. These must be taken into account throughout the whole process of Asset Management because varying levels of risk may be acceptable in different areas of the world, or even of the same region or country. For example, a performance indicator related to environmental performance (say, fish counts) might have a much higher target value in the Highlands of Scotland, than in the South East of England. The methodology proposed in this research allows these socio-economic, environmental and political distinctions to be taken fully into account, alongside more conventional technical engineering factors.

The political and economic demands placed on dam owners are fairly uniform throughout the western world, where schemes are the subject of stringent safety regulation. In addition, the stock of dams tends to be much older than those in the developing world. Nonetheless, while other similarities, such as the level of investment that is available, do exist, there are clear policy differences between different nations. For example, in the United States the majority of dams are under the jurisdiction of the US Army Corps of Engineers (as a result of the River and Harbor Act, 1824, which made the Corps the Federal Agency responsible for navigation and flood control on the nation's rivers) while in the UK most are privately owned. Not only this, but the management of a dam will depend on the exact political and economic climate of the time. Thus, it is clear that there may be more similarities between the management of one nation's dam stock 50 years ago and another nation's strategy now, than between a nation's current management strategy and that adopted in the past.

For this reason, this section is devoted to considering the CMAM challenges that are currently faced by the UK dam industry. Many of the issues that relate to technical challenges are transferable to many other nations, but the core drivers of political policy are unique at any time in any nation. Nevertheless, some societal demands are consistent among a group of nations and this is reflected in the synergies between legislation, as described in Chapter 4.

2.2.2 UK Legislation

A complicating factor in the management of dams within the UK is that the dam stock is unique. Since the country was an innovator in the sector, the dams are among the oldest in the world (ignoring ancient irrigation systems in the Middle East, which are not comparable in cross-section and scale). Therefore, there is no knowledge of how dams of this age should best be managed. This problem is compounded by the fact that the industry is losing expertise in dam design and maintenance.

Perhaps the most demanding challenge facing the hydro-electric dam industry is the need to maximise profit while still maintaining an acceptable level of safety. The dams sector in the UK is subject to strict statutory regulation, although there are anomalies that do cause concern. These are due to the way in which the safety legislation was developed. Popular demand for reservoir safety legislation first came to a head following the disasters that occurred at Bilberry Dam and Dale Dyke in the mid-1800s. The latter catastrophe, which occurred in 1864, killed 244 people and remains the most serious dam failure to have occurred in Great Britain. There was a move at the inquiry into the Dale Dyke failure for

safety of dams to fall under the jurisdiction of a Government inspectorate. However, this was rejected in favour of the responsibility remaining with the engineers and others associated with the works and, although the Waterworks Bill was presented to Parliament in 1866, which would have applied to all reservoirs impounding more than a million cubic feet of ($28,000 \text{ m}^3$), it did not make it to law.

Following two further breach incidents in 1925 (Skelmorlie in Scotland, and Eigiau & Coedty in Wales) which together claimed a further 21 lives, legislation was finally passed in 1930: The Reservoirs (Safety Provisions) Act. As with the earlier Bill, the act applied to all reservoirs above a certain capacity (in this case 5 million gallons, or $22,700 \text{ m}^3$). It introduced the system of panel engineers who were to design, build and inspect reservoirs under the Act. The use of reservoir volume as a way of determining which reservoirs should be subject to the regulation of the Act was continued in the new Reservoirs Act enacted in 1975. The demand for the new act was driven by concern following several reservoir disasters occurring abroad, despite the fact there had been no loss of life due to dam failures in Britain since 1925.

The use of a reservoir volume as the indicator of whether or not a reservoir falls under current British legislation is a consequence of the historic pattern of dam failures. With the exception of the failure of the Darwen dam in 1848, all the reservoirs that have led to loss of life in Britain have had capacities of more than $25,000 \text{ m}^3$. However, a real concern for modern day safety experts is that this figure does not take into account the danger presented by a particular dam. Clearly, the location of a dam will also have a great effect on the number of People At Risk (PAR). A smaller reservoir located in or near a city, may present a much greater risk than a larger reservoir where fewer people live in the area that would be flooded in the case of a dam breach.

The Reservoirs Act 1975 was implemented between 1983 and 1987 and applies to all reservoirs that hold more than $25,000 \text{ m}^3$ of water above the natural level of any part of the land adjoining the reservoir, known as “large raised reservoirs”. There are approximately 2500 reservoirs in the UK that fall under the Act. The Act and associated Statutory Instruments together provide the legal framework within which decisions relating to the safety of reservoirs are made. Four bodies are responsible for ensuring that the construction and operation of the reservoir is safe. These are:

- (i) The undertakers (the owner and operator);
- (ii) Enforcement authorities (who check that legislation is complied with);
- (iii) Qualified civil engineers (who advise on safety); and

- (iv) The Department for Environment, Food and Rural Affairs - DEFRA (formerly the Department of the Environment), who legislate.

The post of Supervising Engineer was also introduced under the act (Sims and Parr, 1998). Supervising Engineers are panel engineers who oversee the day to day running of the reservoir system. Periodic inspections by Inspecting Engineers ensure that recommended works are undertaken and that the reservoir is in a “safe” condition, even though there is, at present, no definition of what is meant by “safe” (Brown and Gosden, 2002). This issue is discussed further in Chapter 4.

2.2.3 *Uncertainty in Existing Guidance*

At present there is a great deal of debate in the dam sector regarding the methods that could be used for assessing and managing risk. Given the great investment of time and money required to carry out a quantitative assessment of the condition of, and risk posed by a dam, it is not surprising that there is a reliance on qualitative methods. Indeed, even those who have undertaken a “quantitative” assessment admit that there are elements of estimation and assumption involved (not least because many of the key failure mechanisms, such as piping are not fully understood and are difficult to predict or detect). Chapter 4 contains a description of the current best practice with regard to ensuring the safety of dams and those who live downstream of them.

One of the key issues relating to quantitative assessments is that there is some uncertainty inherent in Asset Management that arises from conflicting guidance. For example, there is currently a great deal of debate regarding the move from the FSR (Flood Studies Report) of 1975, to the FEH (Flood Estimation Handbook), published by the Institute of Hydrology in 2000. The FSR, upon which the spillway capacity design guide included in ‘Floods and Reservoir Safety’ (ICE, 1996) is based, advises that highest hazard dams be provided with spillways capable of passing the Probable Maximum Flood (PMF) while lower hazard dams be designed to pass a flood with a probability of occurrence of 1 in 10,000 in any year. The FEH, on the other hand, presents information only in the probabilistic 1:T year event format and ignores the deterministic PMF. It uses different statistical methods from the FSR and includes additional rainfall and flood information collected since 1975. The great FEH v. FSR debate centres on the fact that the FEH generally results in substantially greater rainfall and flood peaks over most of the UK, with the 1 in 10,000 year events generally exceeding those of the Probable Maximum Precipitation by up to 60% (MacDonald and Scott, 2000). Clearly, this is an issue of great importance to dam owners as the cost of increasing spillway

capacity for a stock of dams would be considerable, but failure to follow current ‘Best Practice’ is generally not an acceptable option.

While there is some debate as to how large a flood the dam should be able to withstand, the hazard is at least a familiar one for the UK dam owner. In recent years, the threat posed by earthquakes has also been increasingly recognised, and guidance is in place. However, there is no less controversy relating to this issue than there is to flooding. While the consideration of earthquakes is relatively new in the UK, it is a sign of the degree of seriousness with which the safety of dams is viewed. There is currently no widely accepted guidance relating to the management of newly recognised threats, such as terrorism, but these factors do add to the uncertainty faced by decision-makers. This has led to an inconsistency of approach, with some dam owners choosing to ignore the possible risks, while others have been investing in detailed studies into the susceptibility of their assets to these risks. For example, current best practice organisations, as described in Chapter 4, carry out inundation studies, but these are also the subject of debate. While in other countries with a longer societal consciousness of flooding, due to their coastal terrain (Holland, for example), the risk of flooding is widely acknowledged and evacuation plans are publicised, even to the extent of “possible flood level” markings being placed on trees and lampposts, those UK dam owners who do carry out such studies tend to keep them out of the public domain. Others argue that inundation studies should not be carried out, fearing that the mere existence of proof of prior knowledge of the possibility of a catastrophic flooding event would open up the dam owners to litigation.

New guidance for dam owners leads to a pressure to invest in “improvements” to the dam, designed to make them safer. Unfortunately, it is not always clear that measures such as increasing spillway capacity are reasonable in relation to the reduction in risk that can be achieved for the resources invested (Hartford, 2000). The UK safety legislation, driven by the Health and Safety Executive (HSE), requires organisations to reduce risk to a level that is “as low as reasonably practicable” (HSE, 2001), which, being a qualitative assessment, does not leave the dam sector clear as to the extent of measures that should be undertaken.

In addition to the tendency to continually “improve” dams, there is also the question of monitoring. The Reservoir Act, 1975, (Sims and Parr, 1998) places the responsibility for the safety of a dam on the shoulders of the individuals who supervise and inspect it: the Supervising and Inspecting Engineers (see Section 2.2.2). The individual responsibility that the Act places on engineers involved in safety assessment is regarded as an enduring strength of the now aging legislation. However, there is some concern within the industry that this

method of regulation, while so far not resulting in any deaths from dam breach, has meant that modern methods of risk and hazard management (see Chapter 4) have been slow to be incorporated into the dam sector. In addition, the tendency is for each Inspecting Engineer to suggest further monitoring measures that could be undertaken, when they are concerned about declaring the reservoir “safe”. Anecdotal evidence suggests that it is very rare that such decisions are reversed and monitoring removed.

There is therefore a situation where some measurements made by the owner may not be contributing to the understanding of the condition of the asset because the processes being measured are not fully understood. An example of this is where the movement of a dam, relative to the valley sides, is recorded through surveying techniques, yet no movement is detected because, although the dam is moving, the valley sides are also sliding along the valley. Currently there is no structure in place that enables owners to robustly argue against such measurements, and there is a tendency to record everything suggested by the Inspecting Engineer, even if it is felt that the measurement may have no meaning. In addition, because risk-based methods are not yet fully-adopted, surveillance tends to take place at regular intervals, rather than being based on the current condition of the asset, or its rate of deterioration.

2.2.4 Mechanical and Electrical Systems

Of course, a hydro-electric dam system consists of much more than the dam structure and the reservoir. The safety and reliability of many of the mechanical and electrical systems within the dam are quite well understood. This is mainly due to the fact that many of these components are built in factories where they have been repeatedly tested for robustness and reliability. In addition, there are clear guidelines on the safest way of working with electricity and mechanical parts. Nonetheless, there are still important decisions to be made, which are not trivial. For example, during refurbishment some electrical components are replaced with new versions. This builds in a possible unreliability (due to the new components not being familiar to the technicians in charge of them) and lack of repairability (due to units being designed to be disposed of when not functioning, rather than repaired). In previous years it has been possible to take parts from one power generation set to replace in another, but with the advent of new technology, redundant (spare) systems must be incorporated because it is not possible for operators to carry out ‘on-the-spot’ repairs to ‘disposable’ electronic components.

Other components of the dam, such as valves and gates, are mechanical but are often unique to that particular asset. Since they are responsible for helping to control the flow of water in the event of a flood, they are critical to the robustness of the structure and the safety of the people downstream. Large drum gates and other structures related to the control of flow over the dam are subject to the same inspection as the dam body. Therefore, once again, the assessment of whether or not these elements are “safe” tends to be based on expert judgement and engineering experience.

In the same way that the understanding of the dam and reservoir is being compromised due to the age of the structures and the loss of experience from the industry sector, the retention of corporate memory for maintaining and operating other elements of the hydro-electric system is also central to ensuring their continued safe operation.

2.2.5 *Complexity of the Problem Domain*

There is some reluctance in the dam sector to adopt reliability methods widely. Amongst the rather complex reasons for this reluctance (Blockley 1999a) are the recognized limitations of existing models of failure mechanisms and scarcity of data. A very real problem in the hydro-electric dam industry is that, even where data do exist, they are not collected in a form that facilitates analysis. Many measurements, such as reservoir leakage readings (made using a V-notch), are recorded faithfully, but, due to lack of resources, may not be plotted for trend analysis until the concern that they highlight is already evident from some other source of evidence (e.g. a neighbour’s report). Thus managers are sometimes distracted from long-term strategic planning by incidents that require “fire-fighting”.

The complexity of hydro-electric dam systems means that it is essential that experts from different disciplines (civil, mechanical and electrical engineers as well as economists, environmentalists and those with knowledge of governmental policy trends) work together to resolve a complicated set of technical, economic and environmental demands (Hsieh and Liu 1997, Chowdhury *et al.* 2000, Hastak and Abu-Mallouh 2001). In practice, the scale of the problems necessitates that individuals engage in cycles of decision-making in their own domain, which feed into an overall framework of administration and resource commitment for managing the asset system as a whole (Mintzberg *et al.* 1976, Boland *et al.* 1990).

One of the major challenges facing managers of complex assets such as hydro-electric dam systems is that it is very difficult to get people with different types of expertise to communicate effectively. The danger then occurs that many managers tend to see their

organisations vertically and functionally and will manage them accordingly. For example, where a decision requires the input of several units, the manager may meet with each unit on a one-to-one basis, establishing goals for each function independent of the others. Due to lack of time and other resource constraints (such as geography), meetings between functional units may become limited to budgets and activity reports. The traditional ‘departmental’ organigram can lead to “silo” thinking (Rummler and Brache, 1995). ‘The “Silo” Phenomenon’ consists of “silos”, which are tall, thick, windowless structures, usually built around departments, that prevent interdepartmental issues from being resolved by cooperation between colleagues who are not at the top level of management (and who would thus have access to all parts of the organisation). Thus managers within each silo who require the cooperation of colleagues in other silos are forced to pass the problem upwards for top level managers to negotiate a way forward. This means that people within particular departments are often found to be battling against other departments within the same company.

The silo culture forces managers to resolve lower-level issues, taking their time away from higher-priority customer and competitor concerns. Individual contributors, who could be resolving these issues, take less responsibility for results and perceive themselves as mere implementers and information providers. This scenario is not even the worst case. Often, function heads are so at odds that cross-functional issues don't get addressed at all. In this environment, one often hears of things “falling between the cracks” or “disappearing into a black hole”.

(Rummler and Brache, 1995)

This is not a phenomenon that is restricted to the hydro-electric dam industry, of course, but is a global problem. However, it is particularly important in this sector where disagreements and oversights could result in the loss of many lives, as well as having financial implications that could send the organisation into the courts and bankruptcy.

As with many sectors, one of the key challenges facing this industry is to determine a way that different people within the organisation communicate in order to resolve CMAM challenges. Of critical importance is the fact that, while any company within the industry may have a goal of making money (Goldratt, 1993), safety must be a function of all decisions made. Therefore there is an inherent challenge of how those concerned with ensuring the safety of those working for the company and those living within the vicinity of the reservoir can be matched with the responsibilities of those ensuring that the finances ‘add up’. This is an interesting and complicated area that still requires research, not only for this sector, but also for other power generating industries (nuclear, fossil fuel), for the transport sector (particularly in the light of recent tragedies in the rail sector) and for health providers. Fundamentally, the question our society is faced with is “How much is a human life worth?”.

How can we go about carrying out cost-benefit analyses on reducing the risk of death. Is it quantifiable? Is it ethical to put a financial-value on a human being?

There is a core belief within the hydro-electric dam sector that, while fiscal resources are of course finite, the death of a human being in the pursuit of electricity is not acceptable. There is a need for a methodology that categorically states that loss of life is not acceptable, and at the same time provides guidance into the “best” place to spend money to achieve this, while balancing the need for profitable and sustainable electricity provision.

In common with other sectors where safety is a core issue, there is a need for transparency in decision-making. In this way, if a failure (financial, environmental or safety-related) were to occur it would be possible to determine what decision had led to that failure and help ensure that such key decisions are carried out better in the future.

Decisions currently made within the dam sector (and other industries) are generally the result of negotiations between several experts within the organisation (e.g. financial, engineering etc). In order that the people accountable for the decision can be identified there must be some transparency and tractability in the decision-making process. Currently, this is not the general practice.

2.2.6 Strengths and Weaknesses of Decision Support

In order to make decisions, it is first necessary to identify the options available. These can then be analysed and evaluated using expert judgement and other sources of evidence. Now that computer-processing power is widely available and affordable, there are increased possibilities for the development of Decision Support Software (DSS) to help with engineering decisions. The advantages of such systems are that they can (Turban and Aronson, 1998):

- Assist in the formulation of alternatives;
- Provide access to data;
- Allow the development of models;
- Aid in the interpretation of results; and
- Support the selection and analysis of options.

However, the output of the DSS is dependent on the data entered into it, the conceptual, logical and functional models (including user insight) on which they are based, and the way that the software has been developed and configured. These are issues that are not always

fully understood by the user. Within the hydro-electric dam sector, as with other engineering fields, there is a concern that some decisions are being made on the basis of faulty information, which has been taken as “fact” from DSS and other computer tools, such as Finite Element Analysis programmes. In order to overcome this, and due to the fact that the amount of quantitative information upon which engineers can make asset management and condition characterisation decisions is often limited or poorly managed, expert judgement must be used to determine the meaning of the output from DSS tools and other data. In essence, therefore, the DSS does not provide “all the answers” but must be used in the same way as other sources of evidence, with care and prudence that arises from experience.

Throughout the course of this research it has become clear that experts are frequently presented with a plethora of data, but little information. This is because the data being collected may be at the operational level and not effectively propagated up through useful performance indicators to the tactical and strategic levels of decision-making.

It is still general practice for many direct measurements taken on site (such as seepage, water levels, condition of generator magnets etc.) to be kept on site, and in a paper-based system. Those pieces of evidence that are recorded electronically tend to be placed in databases belonging to the particular type of asset to which they relate. For example, data relating to the performance of the M&E systems associated with a gate (in terms of whether it operates when the relevant remote signal is given) may be stored separately to data relating to the physical condition of the asset (e.g. size of cracks, condition of paintwork etc). This presents a problem when particular data is required to inform a decision, as the decision-maker may not be able to easily locate the information, or, worse still, may not be aware that it exists. This could occur when several databases relating to a particular asset are located within one business stream or department, but is even more likely when evidence is split across two or more “silos”.

Even when quantitative data is available and thought to be reliable, there is a further obstacle to their use in supporting decisions. This is because the evidence will be collected and stored in a range of formats and is likely to be associated with a particular dimension (e.g. length, displacement, acceleration, location etc). The information required may also be hidden among other data that are not required for the particular decision being made at the time, as would be the case, for example with the outputs of dense numerical modelling results. It is therefore important to establish hierarchies of performance indicators to ensure that the correct information is being provided to the appropriate decision-maker. This idea of “data” and “meta-data” (data about data) is considered as part of this thesis.

The distance between the person taking the measurement and the decision-maker making use of the data is also a concern. This scenario means that the manager may not be aware of the competence and skill of the person taking the measurement and will therefore not be able to deduce how much credence should be given to it. This is an equally unsatisfactory situation for the person taking the measurement; since if they are not aware of the importance of the data, they could be forgiven for not being particularly motivated to ensure that it is collected in a timely and accurate manner.

Qualitative evidence can be even harder to evaluate and incorporate into the decision-making process than quantitative information. A good deal of valuable information can be hidden in the text of technical reports, historical records of analogous cases, expert judgements and even the perceptions and value judgements of a wide group of stakeholders (such as shareholders, neighbours, fishing clubs, environmental groups and so on).

Since the evidence needed to inform a decision is available in such a wide range of forms, which are not easily compressed into a single format, the current tendency is to choose the most conservative option, based on expert judgement, and then negotiate that downwards when it becomes apparent that the resources are not available for that option to be implemented. It is not currently feasible to fully incorporate evidence that is only partially related to the decision in hand, or that is incomplete, of limited reliability or which is conflicting.

Despite all these barriers to effective and reliable decision-making, experts in this field are becoming increasingly aware of the need to understand the threat that their lack of certainty about the available evidence poses to safety and the reliability of their decisions. Despite being a traditionally conservative sector, organisational and cultural changes in the dam sector are driving a demand for improved decision-making support tools, so that:

- Money can be spent effectively;
- Adverse impacts of management decisions can be minimised and mitigated; and
- In-house experts can be utilised efficiently.

This last point has become more important in recent years due to expert knowledge gradually being transferred from within an organisation to external consultants in an attempt to reduce costs. This, coupled with improved modelling techniques and communication systems (including email) has resulted in decision-makers facing intense information processing

demands (Hall and Davis, 2001). The current best practice upon which these decisions are made is laid out in more detail in Chapter 4.

2.3 Case Study

The case study at the centre of this thesis was loosely based on Scottish and Southern Energy plc, who part-sponsored this research. As the UK's largest generator of conventional hydro-electric power they are recognised as being leaders in the asset management of dam systems. However, the company has some CMAM issues that are different to the rest of the UK and to which they have to pay particular attention. This is because, of the 92 dams that they own (84 main dams, 56 in the ICOLD register) the majority are built of concrete, whereas in the rest of the UK most dams are embankment dams. SSE are responsible for 45 concrete gravity dams and 4 buttress dams. Allt na Lairige is particularly unusual: it has an exceptionally thin section, since it is constructed from prestressed concrete.

Having a dam stock that is generally built of concrete presents special challenges when it comes to maintenance, monitoring and carrying out risk assessments. For example, the pattern of the breach is quite different to that of an embankment dam, and whilst a lot of research has gone into the effect of an embankment dam breaching, far less work has been carried out with reference to gravity dams. Therefore, while the dams benefit from not having the uncertainties associated with embankment dams (particularly piping and hydraulic fracture) there is a good deal that is not known about their behaviour, due to the lack of research that has been undertaken.

The breach of an embankment dam can be assumed to result in a triangular shaped pattern. For concrete dams, this assumption is not valid. Concrete dams can allow a good deal of overtopping before they breach, and even at failure, there are many ways that the dam could fail. For example, it is possible to assume that only one block of the dam may be dislodged, or that more blocks be dislodged, or that the whole dam may collapse entirely. The problem is thus quite complex.

Added to this are the (potential) instances where the dam structure itself does not fail, but where some element of the dam, such as a gate, fails, perhaps due to a mechanical or electrical fault, or wilful damage (through vandalism or terrorism), which could also have disastrous effects on the area downstream of the dam.

As well as providing a case study for research into the difficulties of asset management in the hydro-electric dam sector, Scottish and Southern Energy plc, as a forward-thinking organisation, involved in research, was also able to assist the author in her quest to identify best practice in the industry (as described in Chapter 4).

2.4 Conclusion

The CMAM challenges facing the hydro-electric dam sector can be summarised as follows:

- Constantly changing governmental policy in relation to renewable energy;
- Maximising profit while ensuring safe operation;
- Antiquated safety legislation does not take into account the number of PAR;
- Requirement on panel engineers to declare reservoirs and works as “safe”;
- No clear definition of “safe”;
- Immense cost of carrying out detailed quantitative risk assessment exercises;
- Reliance on expert judgement and qualitative methods;
- Tendency to carry out monitoring that does not inform decisions;
- Trend towards continual “improvement” of assets;
- Inexperience in dealing with recently identified threats from seismic activity or terrorist attack;
- Meeting societal demand for safety (informing without fear-mongering);
- Unique assets (aging dams and ‘one-off designs’ – e.g. not factory-produced);
- Uncertainty regarding and unreliability resulting from the use of new technologies;
- Haemorrhaging of technical expertise and corporate memory;
- Poor data storage methods;
- Disconnected asset condition and inventory databases;
- “Silo” organisational structures impeding communication and effective management;
- Lack of resources;
- Dilemma of carrying out cost/benefit analysis related to the value of human life;
- Opaque and un-traceable decision-making processes mask accountability;
- Misuse of, and over-dependence on, or distrust of, DSS (Decision Support Software);
- Poor communication of top-level objective to people producing KPIs;
- Range of quality and storage formats (including dimensions) of evidence; and
- No coherent methodology for bringing qualitative and quantitative evidence together to inform decisions.

In order to determine how best these issues could be addressed, two related pieces of research have been carried out. Chapter 4 describes the current asset management best practice in the dam sector, while Chapter 5 comprises the most recent guidance on asset management in general. The research methodology used is outlined in the next chapter.

3.1 Introduction

Condition Monitoring and Asset Management best practice in the hydro-electricity industry was investigated through a number of recognised avenues of research. The research essentially fell into two parts:

- Identifying issues; and
- Creating and testing solutions.

Although there is a great deal of information available in the public domain regarding details of asset management for this sector (see Chapter 4) it is not feasible to understand the global issues involved through reading alone. The author was extremely privileged to be supported in her research by Scottish and Southern Energy plc (SSE), which, as the largest generator of hydro power in the UK, is recognised as being a world leader in the condition monitoring and asset management of reservoirs, dams and appurtenant works.

This aim of the research process was to develop a robust methodology for creating process-models, which could support the use of systems-thinking within the engineering sector. This in turn should assist decision-makers in making more robust and defensible decisions by highlighting, acknowledging, and reducing, where appropriate, areas of uncertainty in their knowledge.

The work began with a period of domain exploration, during which the author identified the key issues faced by SSE and other engineering organisations. The key findings from this research are recorded in Chapter 4. Following the formal three years of research, the author has also had the opportunity to test the proposed systems-modelling approach with clients in the rail, sewage and highways sectors. The methods used in the original case study with SSE were tested and extended with the Solutions Focus methodology (Jackson and McKergow, 2002) and improved use of workshops. For the interest of the reader, all the methodologies used thus far are described in this chapter, along with the Repertory Grid Analysis (Turban and Aronson, 1998), which this author sees as a useful tool for further development of the work contained in this thesis.

3.2 Defining the Problem Domain

The case study undertaken at Scottish and Southern Energy, plc was sponsored by the Engineering Department. However, it soon became clear from background reading in the principles of systems-thinking (Chapter 6), that this business unit could not be seen in isolation (see discussion below with reference to Kaplan and Norton and the Balanced Scorecard). The two questions that had to be taken into account in defining the scope of the system to be considered were:

- How wide?
- How deep?

3.2.1 *How wide?*

In order to gain an understanding of the process being undertaken at Scottish and Southern Energy, plc it was necessary to elicit knowledge from experts. In line with modern systems thinking (Senge, 1997; Brown, 1992; Rummier and Brache, 1995; Blockley and Godfrey, 2000), the ‘whole is greater than the sum of its parts’. However, the question facing the author was, how ‘wide’ a part of the organisation should be considered? Clearly, an attempt to understand all the processes within the organisation would be outside the scope possible in the course of a limited case study, yet, as the discussion below outlines, systems-thinking should imply an understanding of all possible interactions, thus precluding the notion of studying the Engineering Department in isolation.

As Goldratt and Deming have demonstrated in their own indomitable styles (Deming, 1986, 1994; Goldratt, 1993, 1996, 1997, 2000), attempts to optimise part of the system can result in the sub-optimisation of the system as a whole. Indeed, efforts to optimise non-critical processes will result in no improvement to the efficiency of an overall system, and indeed, focussing on localised ‘improvements’ can reduce performance of the system as a whole (Wheeler, 1993).

The Balanced Scorecard (Kaplan and Norton, 1996a/b; Kaplan 1990) aims to ensure that targets, incentives, resource and budget allocation are properly aligned with the organisational strategy. In this way, it should be possible to ensure that localised performance indicators do support the higher level goals, thus minimising the risk that changes to one process can have an unexpected and undesired effect on the greater system. The Balanced Scorecard methodology differs from that outlined in this thesis in that the first step is to select the appropriate organisational unit (a Strategic Business Unit, or SBU) for

the work, and clarify its place in the organisation through the use of an organigram. This forced breakage from process thinking at the inception of the project, will be discussed later in this thesis. However, the second task is to Identify SBU/Corporate linkages, in order to:

...guide the development process so that the SBU does not develop objectives and measures that optimize the SBU at the expense of other SBUs or the entire corporation. The identification of SBU/corporate linkages makes visible both constraints and opportunities that might not be apparent if the SBU were considered as a completely independent organisational unit.

(Kaplan and Norton, 1996b)

The exact method for ensuring that no such linkages are missed is unclear in Kaplan and Norton's writing, however, the author is of the view that the use of process-modelling can minimise the chances of this happening. In particular, as Rummler and Brache (1995) demonstrate, process-thinking can eliminate the dangers that might occur from areas of performance disappearing into the "white space" on the organisational chart.

Unfortunately, as Deming explains in his seminal work, "Out of the Crisis" (1997), there is no such thing as 'Instant Pudding'. Indeed, he explains that this hope for "quick results without effort and without sufficient education of the job" is one of the key obstacles faced by those wishing to transform western management.

In the light of all the above, the author drew the following conclusions:

1. Failure to understand the interaction between processes can lead to 'improvements' resulting in no change or a worsening of performance;
2. In order for performance indicators to be useful, interactions between processes must be understood; and
3. To understand a process, one should consult with an expert on that process.

The decision with regard to the width of the system to be considered was that top-level processes within SSE should be considered with a 'broad-brush' approach; resulting in an understanding of the key issues and processes, but not following each process down through the organisation. For example, the contribution of conventional power stations to the overall production of electricity would be considered in terms of the effect that this has on the flexibility and profitability of the company, but individual processes relating to the production of electricity in non-hydro schemes would not be considered. The next question to address was the depth (or granularity) in which the hydro-electric processes would be studied.

3.2.2 How deep?

It is important to reinforce the point that the methodology developed through the course of this research is to support decisions, not to make them. To this end, the process is heavily reliant on the participation and knowledge of experts in the decision domain. The Balanced Scorecard methodology (Kaplan and Norton, 1996a/b) advocates a series of interviews, and ‘Executive Workshops’ and ‘Subgroup Meetings’, which include, at various stages; senior management, their direct subordinates, and a larger number of middle managers.

Rummler and Brache (1995) refer to three levels of performance, “Organization Level”, “Process Level” and “Job/Performer Level”; each with its own set of goals, its own design (or structure) and its own management requirements. The strict demarcation of “Organization”, “Process” and “Job/Performer” may not be necessary, or helpful, but the point that is illustrated in that methodology reiterates Deming’s teaching; performance can only be improved by considering all parts of a system, at all levels of the organisation.

Furthermore, Turban and Aronson (1998) define an expert as:

A person who has the special knowledge, judgement, experience, and methods along with the ability to apply these talents to give advice and solve problems....

Therefore, for this research, it was decided that processes should be studied at all levels of SSE. Thus, consultation was not restricted to senior or middle management, but was extended to take in the processes carried out at what Rummler and Brache would call the job/performer level. The author is very grateful to all of those at SSE who took time out of their busy work lives to support this research through supplying information and knowledge to enrich the building of process-models to develop a robust methodology.

3.3 Elicitation Methods

The process of acquiring knowledge from experts is often referred to as ‘elicitation’ (Davis and Hall, 1998). It is a particularly appropriate term because the dictionary definition is “to bring or draw out (something latent)” (Readers Digest, 1987). The person that draws out knowledge could strictly be referred to as the ‘elicitor’, however, this has connotations of illegality. Therefore, other terms are usually used. Kaplan and Norton (1996b) refer to them as the ‘architect’. However, since the aim is to gather knowledge from someone, and since this is the field of engineering, the term Knowledge Engineer is adopted here, defined as:

[A person who] helps the expert structure the problem area by interpreting and integrating human answers to questions, drawing analogies, posing counterexamples, and bringing to light conceptual difficulties.

(Turban and Aronson, 1998)

In his research into decision support systems for the rail sector, Roberts (2001) describes eight core methods for eliciting knowledge from experts.

1. Unstructured Interviews;
2. Structured Interviews;
3. Workshops with groups of experts;
4. Protocol analysis;
5. On-site observation (work-shadowing);
6. Published material;
7. Case studies; and
8. Repertory grid.

For this research the first seven elicitation methods were used. A brief explanation of each technique, with a review of its efficacy, is outlined below. During the last few months of this research, the author became familiar with the technique known as ‘The Solutions Focus’ (Jackson and McKergow, 2002), and has since employed it to great effect in interview and workshop situations. This methodology will be discussed in Section 3.4.

3.3.1 *Unstructured Interviews*

The initial work undertaken during this course of research was conducted using unstructured interviews. There were a number of reasons for this. Firstly, the knowledge area (hydro-electric dam systems) was relatively new for the researcher, and, secondly, the aims of each interview session were to gain a broad understanding of the problem domain. In essence, these preliminary sessions had a two-dimensional goal. They were aimed at establishing a relationship and trust between the researcher and the contributors, and essentially provided the scope for the research. One of the key outcomes was that the researcher was able to begin to define the problem in the expert’s terms.

The advantage of this approach was that it allowed the author to ‘get into’ the problem very quickly, but the disadvantage was that, because the problem domain is so complex, she did not always know what questions to ask in order to help the experts express the most important elements of their knowledge. Sometimes the conversation ended up focussing on minutiae, because these were easier to gain an understanding of than the more complicated issues that came to light later.

The methodology developed through this research assists in providing a simple and robust approach to developing process-models. Later on in the research, and since, the methodology itself provided a structure for interviews (and workshops).

3.3.2 *Structured Interviews*

Once the unstructured interviews had been completed at all the available levels within the organisation, the knowledge engineer adopted structured formats. In the case study with SSE, the structured interviews were developed following background reading and the understanding gained through the unstructured interviews. The structure was required to ensure that the key points were covered with each interviewee. The questions were very simple:

- What is your name?
- What is your job title?
- What do you do on a day-to-day basis?
- What processes do you manage?
- How do you know how these processes are performing?
- What performance indicators (if any) are you responsible for?
- What performance indicators (if any) do you contribute to (collect data etc)?
- Are any of these processes or performance indicators of concern at the moment?
- If you could change anything about your job, what would you change?

The knowledge engineer also followed the guidelines for structured interviews recommended by McGraw and Harbison-Briggs (1989). The advantage of this interview method was that it ensured that the interviewer did not forget any important issues. Despite the support of an interview structure, each interviewee was different and the knowledge engineer had to rely heavily on (and develop) interpersonal communication and analytical skills to ensure that the results were useful.

Since completing the original case study, the set of questions used has been refined and modified repeatedly, and the questions described in the next section, on workshops, are now generally used for one-to-one interviews as they provide a structure without the danger of restricting creativity, which can happen when a ‘ricochet’ of questions, such as that listed above, are used.

3.3.3 Workshops

Perhaps the most enjoyable and productive method for eliciting information from experts is to prepare a workshop session. Initially, this can seem a resource-intensive process because a successful event requires a good deal of planning (venue, coffee, etc), and the client is asked to make a number of employees available at the same time. However, in practice, this method is the most efficient. It is, in fact, a living example of how a system (in this case, the knowledge network of a group of experts) is much greater than the sum of the parts.

In their paper, Davis and Hall (1998) demonstrate the value of workshops held with groups of experts. The anecdotes in Blockley and Godfrey's "Doing it Differently" (2000), provide vivid examples of the strength of this technique. During the initial period of research, upon which this thesis is based, the use of workshops was limited to those conducted annually as part of the CMAM project. The failure to carry out workshops at SSE offices was mainly due to the state of flux in which the company found itself at the time of the research, and partly due to the inexperience of the knowledge engineer (the author).

However, since completing the main bulk of research into this area, the author has been fortunate enough to be able to continue studying in the 'laboratory of life'. As the facilitator at a number of workshops with water companies, train operating companies and local authorities, the author has now built up a wealth of experience in this area.

As mentioned earlier, under the topic of Structured Interviews, these workshops follow a semi-structured format. Participants are asked to carry out a small amount of preparation for the sessions. This includes answering (or attempting to answer) the following questions:

- In your view, what is the top process in your organisation?
- What processes are you involved in (or in charge of)?
- What are the main Performance Indicators (PIs) that help you to measure how well those processes are performing?
- What do you consider to be the Key Performance Indicator (KPI) for each process; and why?

These questions usually result in some interesting answers. The first question is attempting to ascertain the top-level process of an organisation; which should be in line with the strategy. However, in practice, it is clear that many people who work for certain organisations do not have a clear understanding of the ultimate aim of the organisation.

It is interesting to note that people at lower levels within an organisation frequently find it difficult to identify the processes and performance indicators with which they are involved. However, once the workshop is underway, they, and more senior colleagues, soon become impressed with the complexity of the problems and issues that these ‘performer level’ staff manage.

In order to stimulate discussion and to keep the session enjoyable, positive, rewarding and memorable, the Solutions Focus approach provides a flexible but stimulating structure to the session.

3.3.4 Protocol Analysis

Protocol analysis is a form of process tracking, which attempts to track the reasoning process of an expert (Turban and Aronson, 1998). The essence of the technique is to ask an expert to verbalise their decision-making as they perform a particular task. The ‘thinking out-loud’ can be recorded efficiently with a tape-recorder, or a skilled note-taker.

This technique of capturing the knowledge of experts was one of the main ways in which the research at SSE was carried out. Examples of tasks that were studied in this way are the use of particular databases and the conduct of dam inspections. A typical statement that was recorded during analysis of database use would be “I click on this button here so that it refreshes the cells in this spreadsheet, so that I know that the data is all up-to-date”.

The information recorded during dam inspections was less detailed, but provided an insight into the way that decisions are made, and, of particular interest, how uncertainty is managed. For example, one Supervising Engineer commented, “I’ll just compare those little cracks on the dam with the sketch I made last time I was up here. Yes, I thought so, there hasn’t been much change. I’ll just measure this longer one, to check. No, that’s fine. There hasn’t been any change to this for years, but it’s best to just make sure”. On the same occasion, the engineer had to make a decision about when the next underwater inspection should be undertaken. The record for this explains how he managed the uncertainty inherent in managing hidden assets.

3.3.5 On-site observation (work-shadowing)

Work-shadowing is similar to protocol analysis, in that it involves observing the expert at work (Turban and Aronson, 1998). However, the main difference is that the expert is not required to verbalise decisions. Generally, this resulted in the Knowledge Engineer asking

questions after the event to ascertain the reason for certain actions being taken. The danger with this method is that often the knowledge engineer, being less experienced in the problem domain, does not always know which questions to ask to gain insight into the decision. However, in many situations where protocol analysis is not feasible, work-shadowing can provide benefits. Situations where this is preferable to protocol analysis would be those where the expert is uncomfortable, unwilling or unable to verbalise their thought process. or where this would be inappropriate, for example, when another person is within earshot.

The method can be taken further by making a note of the expert's motor and eye movement. In other words, recording where they walk, what they touch, what they say and what they look at while making decisions. The advantages and limitations of this method can be found in McGraw *et al* (1989). This level of observation was not employed in the SSE case study because the knowledge engineer was not experienced in its use and would not have been able to be certain that her view of how the decision was made tallied appropriately with the true explanation.

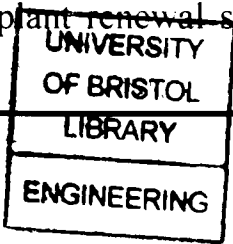
3.3.6 *Published material*

Perhaps one of the easiest ways to quickly gain an insight into the issues related to a particular field of work is to study written material associated with that field. One of the main advantages of this technique is that it requires minimal input from the expert. In addition, a large volume of information can be sifted for key facts, while at the same time giving an overview of the breadth of issues related to the problem domain.

However, there are a number of problems with this method. Not least is the fact that to the non-expert, some written information can be difficult to understand due to a lack of technical knowledge, or the use of jargon and unexplained acronyms. In addition, one of the main difficulties faced at SSE was the need to verify which pieces of information were publicly available and which were confidential for commercial reasons.

Nonetheless, this method proved helpful, particularly at the beginning of the research, because the experts at SSE made an effort to ensure that the knowledge engineer was able to access the information she required, and that this material was put into context of the wider decision-making domain at the company.

The documents studied ranged in detail from high-level strategic documentation, through tactical thinking (such as inundation study reports and plant renewal strategy documents),



right through to records of operational activity. These included: records of completed work, such as maintenance activity; drawings and designs of plant and their components; and policy documents, outlining, for example, the inspection intervals and procedures for particular types of assets.

Literature reviewed to determine best practice in the sector include:

- Technical journals;
- Conference papers and proceedings;
- Historical records; and
- Company documents.

3.3.7 *Case studies*

The seventh method used to elicit knowledge from the experts at SSE, was to look at particular case studies. This also relates well to the Solutions Focus, which is described below, because it involved asking the question, “How did you manage an analogous case in the past?” Much of the information that was gathered for these case studies was taken from published material, however, it also involved asking technical experts and managers about their recollection of particular events.

It soon became clear that case studies are also an important tool for the experts at SSE. They use the same methods of reading, attending conferences, consulting with colleagues and other experts to ensure that they follow what is considered to be current Best Practice. However, much of the information that they use to carry out their work is what is known as tacit knowledge; the knowledge that they store in their own heads. This has a serious implication for the future management of the dam-related assets, as those experts begin to retire.

3.3.8 *Repertory grid*

Repertory Grid Analysis (RGA) is basically a method that uses a table to demonstrate how an expert makes a decision (Turban and Aronson, 1998). It captures their view of the key attributes of any given ‘object’ and allows them to express the desirable traits for that object. Each attribute can be weighted according to how important the expert believes it to be. Scores are given on a scale of 1-3 or 1-5 depending on how closely a particular option (‘object’) meets that trait. For example, an RGA for choosing a car might be as shown in Table 3.1.

| Table 3.1: Example of an RGA Input for choosing a car | | |
|---|------------------------------|-----------------------------|
| Attributes | Desirable Trait (Score 3) | Opposite Trait (Score 1) |
| Speed | Fast | Slow |
| Reliability | Reliable | Unreliable |
| Cost | Cheap | Expensive |
| Looks | Beautiful | Ugly |

The output grid for the decision is given below, in Table 3.2. Please note that only a make has been given, not a model, so the results provided are purely imaginary and do not in any way imply a slur on any particular manufacturer!

| Table 3.2: Example of an Output Grid | | | | |
|--------------------------------------|-------|-------------|------|-------|
| Attribute Make | Speed | Reliability | Cost | Looks |
| Rover | 2 | 1 | 2 | 2 |
| Volkswagen | 2 | 3 | 2 | 2 |
| Ferrari | 3 | 1 | 1 | 3 |
| Fiat | 1 | 2 | 3 | 1 |

If the decision-maker weights all of the attributes equally, then the particular model of Volkswagen will come out ahead. However, if speed or looks are weighted heavily, the Ferrari may be chosen, while the Fiat would be the choice if cost was an overwhelming factor.

RGAs are useful because they provide a numerical valuation related to the expert’s opinion. This makes them ideal for being supported in computer packages (Turban and Aronson, 1998) and for providing an input into automated decision support or expert systems. However, it is clear that the main benefit is to be found where experts are required to choose between two or more options. Hence, because the research at SSE was aimed at establishing a methodology for building process-models, not for constructing a task specific decision-support tool, this avenue was not pursued. Nonetheless, there is certainly value to be gained from further work being undertaken in this area. In particular, with regard to use of the Perimeta approach and software, which will be discussed later in this thesis (Chapter 7

onwards), this formal recording of an expert's view of the relative importance of various attributes could be a useful tool.

3.4 The Solutions Focus

The Solutions Focus is a very powerful methodology that the author has used with clients during sessions aimed at improving the performance of their organisations through the use of systems-thinking principles, which include process modelling. The methodology grew out of systems thinking and has been used successfully in the fields of psychotherapy and counselling, where it is sometimes referred to as "Brief Therapy" (Weiner-Davies, 1993).

Until recently, (Jackson and McKergow, 2002) the approach had been widely used across 'people professions', but is now being applied in management and organisational work. As far as the author is aware, the work that she has undertaken applying the Solutions Focus in the explicit management of engineering assets, is at the leading edge of the application of these ideas.

Essentially, by focusing on solutions, rather than problems, the method empowers people and allows them to open their minds to creative ideas. The tool set comprises:

- Describing the current Platform;
- Visualising the Future Perfect;
- Identifying Counters;
- Determining the current position on the Scale; and
- Establishing Small Actions for improvement.

Since this is an auxiliary component to the original research focus, it will not be described in great detail here. but the reader is referred to Jackson and McKergow (2002) for further information. The author intends to publish some of the findings resulting from the application of the Solutions Focus, in due course. However, the following anecdote should suffice to demonstrate the way in which the Solutions Focus provides structure, direction and energy in workshop situations.

At a workshop aimed at introducing members of the Highways Department of a local authority to a new and more efficient way of improving performance, the Solutions Focus was applied. The Platform described was that the central Performance Management Team were having difficulty in collecting information from certain engineering managers. The Performance Management Team (PMT) described their Future Perfect as being a situation

where up-to-date data was always readily available, reliable, and presented in the correct format.

In order to identify counters for success, the PMT were asked if the Future Perfect had ever happened “even once, in a small way, just for a short time”. The team replied that there were some engineering managers who did report the data on time and in the required format, and that the information was thought to be reliable. Upon questioning the “good” managers, it became clear that they were consistent about reporting the data promptly because they understood that it fed into the Best Value Performance Indicators, which are reported to central government and have an impact upon funding.

Using the Scale, the PMT defined the current state of affairs (10 being the Perfect Future, 0 being failure) as about a 6. By taking small steps to tell the other engineering managers what the information was needed for (it transpired that many people in the field had never heard of Best Value Performance Indicators), it was felt that a jump could be made to an 8. Further counters, such as real-time information systems and hand-held data collection devices were identified as potential counters that could, in the long-term, take the score to a 9 or 9.5.

Once this exercise had been completed, the PMT and other Council members present at the workshops realised the value of process-modelling and participated in the activity with great enthusiasm and increased honesty. As a result of studying the processes, rather than the organigram, at the end of the five-hour session there was a palpable increase in respect, trust and understanding between the PMT and the engineers as the complexity of the tasks and problems, and complicated interaction between processes was revealed.

3.5 Continuous Improvement

As acknowledged in the introduction to this chapter, there were essentially two stages to this research. The first, establishing the problem domain, was achieved through the elicitation methods described in Section 3.3, above. The second part of the work was the attempt to produce a robust method for creating process-models. In fact, as Chapter 9 demonstrates, once the methodology was applied in real applications, the process-modelling became just part of a broader Performance Improvement Cycle (described in Appendix D).

For the creative part of the research, where process-models were created and tested in order to facilitate the development of a robust methodology, the key research principle was that of Continuous Improvement (Deming, 1986; Lepore and Cohen, 1999; The HPO, 2002; BSI,

2000 a,b,c, 2002). The concept is represented by the Deming (or Shewhart) Cycle, shown below in Figure 3.1. This is also commonly referred to as the PDSA Cycle (NHS, 2002).

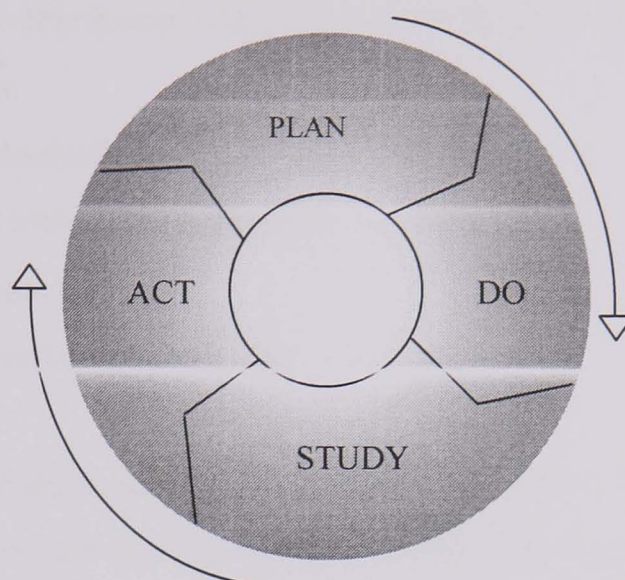


Figure 3.1: The PDSA Cycle

The research method involved assimilating all the knowledge collected about the case study problem domain and then linking this with understanding of systems-thinking (PLAN) to produce (DO) process models. Then each model was tested through consultation with experts and a “demand/response” concept, developed as part of the research (see Chapter 8). Following this period of STUDY a number of areas that could be improved were identified (ACT), and the next iteration begun until, eventually, a robust methodology was developed. This methodology is described in Chapter 8 and tested in Chapter 9.

3.6 Conclusion

This chapter has outlined the research methodology. Essentially, this falls into two parts: establishing the problem domain; and developing the modelling method. The case study was identified and the processes involved were understood through the use of recognised elicitation methods. The case study period with SSE was invaluable in terms of helping to bring all these disparate pockets of understanding into some coherent framework for research. The variety of asset types that make up a hydro-electric dam system make it a challenging area to study. Whereas, historically, engineers were expected to understand and manage the entire asset, modern technology has necessitated a move towards the responsibility being divided into areas of technical expertise. Engineers are now broadly split according to expertise, into the following areas:

- Dams and reservoirs;
- Electricity generation systems (turbines etc.); and
- Electricity distribution systems (transformers etc.).

Even within these broad categories there is still a need for specific expertise. For example, those responsible for ensuring that the dam can withstand the forces to which it is subjected can be further divided into the several categories, examples of which are given below:

- Seismic engineers;
- Flood prediction analysts;
- Geotechnical and foundation engineers;
- Concrete specialists; and
- Gates and other mechanical control.

Contact with SSE allowed the author to spend time with experts from each of these specialist areas. It soon became clear that no one person could begin to understand all of these areas of expertise within the time constraints of one period of PhD study (or perhaps even one lifetime, since technology is constantly progressing). It also became evident that there is a failure in the dam industry as a whole to fully understand how all these different areas of a hydro-electric dam system can be integrated to ensure that money is spent in the most effective manner.

Since the original research was undertaken, the Solutions Focus method has provided a structure for process-modelling workshops with clients from several sectors of engineering. The process of identifying a robust method for building process models involved a combination of extensive reading and the practical application of the concepts of Continual Improvement and the PDSA Cycle.

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Best Practice in the Dam Sector

4.1 Introduction

The investigation into the best practice in CMAM in the hydro-electricity sector was undertaken through a combination of reading (regarding detailed, technical management of individual assets as well as higher-level management tools used in the field, such as risk assessments and other quantitative methods) and direct consultation with experts in the field using the elicitation methodology described in the previous section.

Due to the large amount of information collected during the case study, and the complexity of the organisation, this chapter has been divided into sub-sections in order to ensure clarity for the reader. It is to be noted at the outset that at the time of the research, and through to completion of this thesis the author remains of the opinion that current procedures at Scottish and Southern Energy plc. (SSE) generally reflect the industry best practice. The research methodology used to gather the following information is explained in the previous chapter. The author would like to reiterate her thanks to all the members of staff at SSE who supported this research.

4.2 Organisational Structure

The best practice in the UK hydro-electric industry is based on principles of best practice of management in general. This involves an organised management framework that can match the condition monitoring and management needs of the asset with the professionals who have the knowledge and expertise to address them. This is no trivial task, and has some clear weaknesses as a methodology. Firstly, it encourages the vertical “silo” thinking that has been identified in the previous section as being of concern. The second potential difficulty is that those people who coordinate the various engineering experts may not be from an engineering background (Brown, 1992). Therefore, there is a danger that management decisions may be unduly biased by the perception of the managers, who tend to be focused on ‘the bottom line’ – e.g. making money. While, as Goldratt and Cox (1993) convincingly argue, the goal of an organisation may legitimately be to make money, it is essential that a broad view is taken, including engineering, risk and safety issues, to ensure that this goal can be met in the long term.

The traditional hierarchical organisational structure may have some validity, and history demonstrates that companies with such a structure can succeed in even the toughest macro-economic climate (Ferry, 1993). An important factor that can assist an organisation in being successful is to ensure that the departmental boundaries can be traversed as necessary. Indeed, Rummler and Brache (1995) argue that the conventional company configuration can accommodate a process-based style of working which can be very efficient and effective, so long as the interfaces between the functions are well managed.

4.3 Data, Information and Knowledge

The issue of recording knowledge is complex (Turban and Aronson, 1995) particularly when, as has been described in the previous section, it is necessary to capture and synthesise the knowledge of several experts in order to reach a decision.

A precursor to knowledge is information, and information is dependent on the existence of data. Goldratt suggests that the difference between data and information depends on context. He states that:

“ information is...the answer to the question asked”

(Goldratt, 1990)

The answer is drawn from a body of data, but it requires knowledge to be able to ask the right question. Goldratt (2000) explains that having the technological systems to “manage” data is no guarantee of success. Indeed, he argues that the reason why so many computer software providers boomed in the nineties only to “go bust” is because they failed to address the key requirements of their clients. In other words, they could store and manipulate data, but they did not answer the real questions (perhaps even the client did not know what they were) and thus failed to have a positive effect on the client’s “bottom-line”.

Knowing what the question is depends on expert knowledge, which is when (Turban and Alonson, 1995) an expert brings together his understanding, experience, accumulated learning and expertise to make a decision. This decision will be based on the available information, which can be thought of as being data that has been organised so that it has meaning to the recipient. Data points are “random and miscellaneous” (Wheeler, 1993) and it is only once they are arranged in a graphical manner that they begin to *inform* decisions, and can be said to be *information*.

The following section relates the findings of research into the data and information systems at SSE along with descriptions of best practice and the identification of key issues.

4.3.1 Data and Information Storage in the Dam Sector

The question of data storage in the dam sector has become an important issue in recent years (Lillie and Hitchmough, 1999; Stewart, 2002). The problem is that, historically, records have been kept on paper; frequently at the site of the dam or power station in question. Old management styles, with assets being monitored, maintained and repaired by engineers who were based locally, meant that complete written records were not considered necessary, since most asset information was stored within the memory of an appropriate person. Increasing centralisation of control along with the passing of these ‘founts of knowledge’ has meant that some assets have never been formerly recorded in a corporate database and, even where some written records exist, these have not been compiled into a central database. The task of collating and storing all the documentation is onerous, and, while the Reservoirs Act, 1975, encourages companies to store records and documentation so that they can be retrieved quickly and easily as required, in practice, many dam owners have found other issues to be a higher priority (Stewart, 2002).

4.3.2 Case Study Systems

Scottish and Southern Energy plc, like other leading companies in the water sector (Stewart, 2002), has recently invested extensive resources into updating and completing the record of assets held. In addition, the company is setting best practice standards by storing condition monitoring information and asset management history for the assets. The existing databases at SSE:

- Store information required by the Reservoirs Act 1975;
- Provide an inventory of the assets owned by the company;
- Contain data obtained through surveying and instrumentation;
- Support dam/break studies;
- Detail the known history of the dam;
- Record the work history for other assets; and
- Relate to risk assessment analyses.

In accordance with best practice in data storage, the systems benefit from:

- Controlled, password-protected, access;
- Search facilities;

- Smart functions, such as automated work scheduling;
- Technical support; and
- Continued improvement as required.

The records that were examined during the case study are outlined in Table 4.1 and the key findings are given in Table 4.2.

| Table 4.1: Records examined during the case study | |
|---|--|
| Record | Description |
| The ResAct electronic database | <ul style="list-style-type: none"> • An electronic form of the Prescribed Form of Record required by the Reservoirs Act of 1975; • Can quickly convert readings into graphs, generally produced and examined at least annually; and • Abnormal measurements are noted as soon as they are recorded (although informally) so that action can be taken. |
| Blue information files | <ul style="list-style-type: none"> • Paper records for each and every dam, containing historical records such as inspection reports and correspondence; • Includes information supplementary to the Reservoirs Act, 1975; and • Has proved useful in supporting advances in risk assessment in the sector. |
| Records of instrumentation and monitoring | <ul style="list-style-type: none"> • Inventory and record of measurement frequency for instrumentation on the dam; but • More detailed records usually remain with the contractor carrying out the work. |
| Details of repair and renewal works | <ul style="list-style-type: none"> • These can be found in the ResAct database and Blue information files; and • More details can be found in work-planning systems; but • There may not be a specific database for this information. |

| | |
|---------------------------|--|
| Asset Management Database | <ul style="list-style-type: none">• Detailed database bringing together details of the company's assets;• May support long-term planning as well as providing details of spare plant that could be used if other parts fail;• Frequently stored according to asset type; and• Only a few organisations have integrated systems. |
| Work-planning software | <ul style="list-style-type: none">• Translate medium to long-term plans into shorter-term actions;• Integrate into health and safety system by storing risk assessments for each activity to be carried out; and• Can prevent essential works being overlooked. |

| Table 4.2: Key findings | |
|-------------------------|---|
| Topic | Findings |
| Data Quality | <ul style="list-style-type: none">• The main challenge is keeping data current due to the large amount of data collected;• There are no gaps in the Prescribed Form of Record; but• Historical gaps in other records can preclude the most efficient allocation of resources |
| Planning Support | <ul style="list-style-type: none">• “Real-time” planning only exists at the operational level in the Control Room (e.g. opening and closing valves);• Tactical planning is carried out well in terms of deciding when and how much to generate; but• The link between strategy and investment in assets is not always well defined due to constantly changing economic climates (new legislation) and changes in the management of companies, resulting from these changes. |
| Integrated databases | <ul style="list-style-type: none">• Best practice companies are investing in providing better linkages between existing asset-focused databases; and• The optimum situation is recognised to be one that will support joint decision-making across discipline boundaries, supported by integrated, synchronised systems. |

| | |
|--|--|
| Asset Management Decision Support Systems | <ul style="list-style-type: none">• Expertise and experience is being lost from the sector, so this knowledge must be captured;• A tool could be linked to existing AM databases to provide automated reminders for inspections to be fed into work plans;• Must not be too prescriptive - human decisions will influence the final plan (e.g. weather, temporary staff absence etc.);• Could prioritise based on previous risk/benefit assessments;• May not need to be of the medical “diagnosis” style described by Turban and Alonson (1998); but• Could make use of existing technologies such as the APT (see Chapter 5). |
| Trend analysis and Reliability Centred Maintenance | <ul style="list-style-type: none">• Can be made more effective by ensuring that the data is available for the analysis; and• RCM could result in more efficient decision-making. |
| Security | <ul style="list-style-type: none">• Some people wish to maintain separate systems to reduce the risk of a systemic “bug” but this results in multiple entry of data; and• Modern security practices (e.g. log-in names, passwords, with different user rights) could secure data and ensure tractability. |
| Search Function | <ul style="list-style-type: none">• No longer necessary to create “tags” with letters representing asset type etc. once modern search functions are used. |
| Data and Information Entry | <ul style="list-style-type: none">• Best practice is to avoid multiple entry; and• Documents could be scanned to provide security, improved access, and speed up finding information. |

4.4 Operational Best Practice

4.4.1 Reliability Centred Maintenance (RCM)

The aim of maintenance is to minimise the long-term (or whole-life) cost of an asset. Techniques such as Life Cycle Analysis (Esselman *et al*, 1998, Robery, 1997) and Activity Based Costing (Brandt *et al*, 1998; Cokins, 1999, Day and Kos, 2000; Kaplan, 1990) can be

used to establish which maintenance strategy will result in the lowest cost to an organisation. This approach considers two types of cost (Wolfson, 2000); “Direct Costs”, the actual cost of carrying out the maintenance activity, measured in terms of labour and material, and “Indirect” or “Consequence” costs. The latter result from the loss of production (and sales) that follows from an asset failing due to a maintenance regime resulting in poor reliability and may not be measurable (Deming, 1986, 1994). Examples might be the incalculable cost of loss of customer goodwill following failures in their electricity supply, or damage to the Environment due lack of compensation flow.

There is a danger in the dam sector that the current maintenance plan may be based on historical practices, rather than a clear analysis of the optimum maintenance regime. This can result in costs rising unchecked as plant ages. While work-shadowing at SSE, the author identified that there are a number of engineers who have a particular “knack”, such as restarting an unreliable piece of plant, with methods that are certainly not recorded in the accompanying technical manual. Ideally this knowledge should be captured on a regular basis and fed into existing DSS in order to ensure that best practice is continually developing and improving.

4.4.2 Sector-wide research

Thanks to the foresight of dam owners sponsoring research, gaps in organisational Knowledge Management are ameliorated by a sector-wide knowledge-sharing, which has led to the publication of useful guides for the management of particular assets, which make it possible to link maintenance activity with reliability in a meaningful manner (e.g. US Army Corps of Engineers, 1997). However, as that document warns, the data collection and investigations needed to assess reliability are extensive. For example, the equipment design, use, history and future demands are required. Appendix B of “Reliability Analysis of Hydropower Equipment” (USACE, 1997) lists the information required as follows:

- Historical unit availability and operation;
 - Any equipment derating;
 - Accident reports;
 - Operation and maintenance records;
 - Equipment performance tests (original, interim, and current);
 - Periodic inspection reports;
 - Design and construction reports;
 - The operation and maintenance manual; and
 - Turbine model test reports.
-

The methodology also recommends thorough site investigation conducted by hydropower technical experts, to include equipment inspections and project personnel interviews. However, even with this great body of information, the document cautions that:

“It is also important to identify the priorities and concerns of the project personnel and utilize engineering judgement in evaluating equipment condition”.

(US ACE, 1997)

Hence, despite the array of tools available to assist in the decision-making process with regard to maintenance regimes, all of these, whether they be behavioural studies such as Vibration Analysis; risk assessments using Failure Modes Effects & Criticality Analysis (FMECA), Fault Tree Analysis (FTA), Cause and Effect (Fishbone/ Ishikawa Diagrams); or predictive models, such as Bath Curves and Bell Curves depend on the judgement of the engineering expert (Dale and Bunney, 1999).

4.4.3 Risk-based Surveillance

In order to maximise the use of resources, best practice organisations use risk-based methodologies for allocating surveillance. This applies not only to the monitoring of generation plant and other mechanical or electrical equipment, but also to the surveillance of the dam as a whole, as will become clear in the following sections.

4.4.4 Determining Operational Strategy

Due to the unique nature of hydropower generation it can be very difficult to accurately ascertain the efficiency of the system. This is because, while the efficiency of a gas or steam turbine can be predicted through the use of models that match measured data to that calculated by energy balance equation (Gay and MacFarland, 1999), the inputs to a hydro-electric set are not so easily measured.

Although the economics of a particular type of turbine, or configuration of turbines (such as using twin turbines in low flow situations) can be calculated, there will always be uncertainty with regard to the running efficiency of the system. This is because the efficiency does not relate only to the ratio of production to flow. Rather, wider considerations, such as the management of the reservoir level and timing of electricity generation, must be considered. For example, there may be occasions where rainfall is lost because the existing reservoir level was high and the precipitation flowed through the spillway. Conversely, an opportunity to sell electricity at a good profit (due to demand from the Grid) may be missed

if the reservoir level is so low as to prohibit generation, or limit generation to the compensation sets.

The economics of the electricity market have resulted in a need to produce energy at short notice, in order to capitalise on the payments available. This has led to a reliance on quick-start systems, which results in increased wear to the mechanical elements of the system. This trade-off between flexibility and maintenance costs is constantly monitored to ensure that the company continues to follow the most profitable strategy possible in relation to the ever-changing economic demands and rewards.

There are obvious benefits that would result from a framework that would allow technical experts, experienced in the performance and operation of a particular piece of plant, to communicate effectively with the financial specialists who suggest that ‘quick-start’ systems are the way forward, so that together they can decide on the optimum strategy for short-, medium- and long-term gain.

4.5 Dam Safety

4.5.1 Defining Dam Safety

Ultimately, the statutory requirement is that an Inspecting Engineer, acting in accordance with the 1975 Act, should declare a dam “safe”. This judgement is largely based on the use of experience to interpret the significance of written records and observations made during a visual inspection. Unfortunately, while the Act makes references to safety with regard to a reservoir that is unsafe and to the Enforcement Authority having the powers to take immediate action “to protect persons or property against an escape of water from the reservoir”, it does not give any specific definition of what is meant by the term “safe” or “safety” (Gosden and Brown, 2000).

There are a number of issues that are brought to mind when considering the topic of Dam Safety. It is essential to distinguish between the safety of the dam structure and that of people who live downstream of it. In addition, those people who work at the power station, or use the dam as an access route (as is the case at Pitlochry, for example), should also be considered.

Risk to Stakeholders

Many dams are sited in remote locations, which means that, while remote surveillance is in place in the form of CCTV, it is almost impossible to prevent people trespassing on the dam. Due to the size of the structure and the nature of the currents that can be found around inlets and outlets, those who trespass on the dam or swim in the reservoir without proper permission are putting themselves at risk.

There are a few locations, such as the dam in Pitlochry (which with its fish-ladder is the fifth most visited attraction in Scotland), where the general public have rights of way, even across the dam crest. At these sites special care is taken to ensure that risk assessments are undertaken at regular intervals in line with the HSE's guidance (HSE, 2001, 2002a/b). From time to time, where particularly hazardous conditions are necessary (due to refurbishment, for example), pedestrian routes may be temporarily diverted or closed.

Good practice organisations take care to protect the public during normal operation of the hydro-electric systems when it needs to operate the gates and valves. There may be fishermen, swimmers, or other people downstream from a dam at any given time, so whenever operations, such as the opening of gates for testing and during inspections, may result in a sudden surge of water down the river, care is taken to warn those people who would otherwise be at risk. This can be undertaken effectively through the careful positioning of warning notices, or the use of sirens.

Precautions are also taken to ensure that employees are not put at risk through their normal day-to-day work. This is done, as was mentioned earlier, by enforcing the use of risk assessments when tasks are allocated. Additional precautions, such as "radioing-in" are taken when remote working is necessary. For high hazard tasks, such as underwater working, the company uses specialist contractors, so that the probability of an accident is minimised. At SSE, when people undertaking work on behalf of the company are required to undertake tasks downstream of the dam, they communicate with the Control Room to ensure that there will be no releases of water during that period.

In addition to these every day hazards, perhaps the most important aspect of "Dam Safety" is to prevent loss of life during extreme events. These can be precipitated by the hazards described towards the end of this chapter. It is interesting to note the psychological effect that results in inhabitants downstream of a dam expecting not to be flooded, even during events that would otherwise have led to flooding (if the reservoir had never been formed). While it is true that the presence of a well-managed reservoir can have an attenuation effect,

there is a limit to the extent to which an extreme rainfall event can be stored in the reservoir. These psychological effects, and their consequences with regard to providing flood warnings are an area of research that still requires further work (McClelland and Bowles. 1999).

Risk to Dam Structure

In most cases, because of the traditional design approach applied to dams, it is implicitly assumed that the safety of people on, and downstream of, the dam is dependent on the dam structure remaining intact in the event of an extreme occurrence. However, as the ICOLD Bulletin points out:

...in some cases an owner might find major damage to an existing dam tolerable, provided there is not a catastrophic release of storage which results in flooding that is dangerous to downstream population and property.

(McDonald *et al*, 2000)

This is one of the reasons why, as the ICOLD Bulletin argues, and as the volume of recent literature demonstrates (Charles *et al*, 1998; Sandilands *et al*, 1998; Sandilands and Noble, 1998; Ballard and Lewin. 1998; Hartford. 2000; Hughes *et al*. 2000a/b; Hartford and Stewart, 2002; McQuaid, 2002; Hall *et al*, 2002a/b; Tarrant *et al*, 2002; Attewill and Spasic-Gril, 2002; Brown and Gosden, 2002) the risk-based approach to dam safety is becoming so popular. By considering risk, a dam owner can make decisions that would otherwise have a very different outcome using traditional methods. For example, the great cost to the company that would result from compensation claims and, more importantly, loss of public and stock market confidence, following an event that claimed a human life, may far outweigh the cost of repairing, decommissioning or replacing a seriously damaged dam.

4.5.2 Safety Management

In 1993, the Department of Trade and Industry's Overseas Scientific and Technical Expert Mission Scheme (OSTEMS) carried out a study into Dam Safety in Europe. The study included a review of best practice in seven European countries (Portugal, Spain, Ireland, Switzerland, Austria, Finland and Sweden). The review team stated that:

"We in Britain, as in Europe, are moving into a period in which our major interest in dams is their safe management...Dam safety is not a subject that has a high priority here or in many other European countries".

(Beak *et al*, 1993)

One of the major findings of the study was in relation to the categorisation of dams according to their potential hazard. It was found that Portugal was advanced in this respect, having categories that were defined according to environmental, structural and human

factors. Other countries either had no categories, or up to four (like Britain) related to the likely consequences of failure. The report made two key recommendations (Beak *et al*, 1993):

1. the use of a well-researched all-embracing hazard classification for dams so that resources can be better targeted where they are most needed; and
2. the need for a central enforcement office to be a regulatory agency, a depository for records, a centre for technical standards, a catalyst for training and a voice for dam safety awareness.

As of the time of writing, the second issue, regarding the storage of records has still to be resolved, as it still presents a weakness in dam management systems. Although good practice organisations do store their records in two or more locations (often in paper and electronic formats, like SSE) this is not enshrined in law (Stewart, 2002). Although there is no central enforcement office for Europe, ICOLD (the International Committee on Large Dams) fulfils this role to some extent, supported by national dam societies (McDonald *et al*, 2000).

The recommendation regarding an “all-embracing hazard classification” has been superseded by the work of the dam community’s embracing of risk-based methodologies, particularly in the UK and Canada, which are discussed below. Scottish and Southern Energy plc were one of the first companies in the country to begin investigating prioritisation of works through risk assessment techniques (Sandilands *et al*, 1998; Sandilands and Noble, 1998; Dempster *et al*, 2000). These have formed the basis of what is current best practice in reservoir management, as defined in the recent CIRIA Report C542 “Risk management for UK reservoirs” (Hughes *et al*, 2000a). Both approaches are described below.

4.5.3 *Scottish and Southern Energy Methodology*

As a best practice company, SSE employees are experienced in the use of risk assessment on a day-to-day basis; even the computer systems that keep track of maintenance and repair activity are organised in a manner that facilitates the production of risk assessments when work cards are issued. However, the company has taken the lead in recent years in extending these risk assessment practices to large-scale applications. The theory has been applied to the risk assessment of dam systems, in order to provide a methodology for prioritising spending on civil engineering assets.

The methodology is based on a combination of the inductive principles of a Failure Modes and Effects Analysis (FMEA) and the deductive approach of Fault Tree Analysis (2001a/c). The system has been set up around risk assessment pro forma, so that a consistent approach can be applied throughout the civil engineering division. In the same way that past inspection reports can be used as prompts during subsequent inspections, the risk assessments are also usually filled in on site.

The data recorded in the forms includes the basic inventory information (scheme, reservoir, component name etc). Next, an attempt is made to determine the likely failure mode of each element and the potential triggers that would cause that failure. The engineer carrying out the assessment will try and predict whether the failure of the element will result in a knock on effect or multiple failures. The next step is to make an assessment of the overall consequences that would result from the failure and to identify actions that could be taken to prevent the failure. In the event that there is a significant probability that failure could occur, even once mitigation measures have been put in place, contingency plans are developed.

Another critical element that SSE have developed is the concept of the “detectability” of a failure. SSE use a combination of the time taken for the failure to develop and the probability of the fault being detected before failure as a way of determining how likely it is that repairs can be undertaken in time to prevent the failure. The time taken for the failure to develop also informs the decision regarding the inspection frequency for the asset.

While the Health and Safety Executive (HSE, 2001) recommends defining the risk as the probability of the failure event (hazard) occurring multiplied by the consequence, SSE have added a third component to the equation: the likelihood of detection. In effect, this is part of what the HSE might refer to as mitigation. The more likely it is that the hazard will be detected (and mitigated) the lower the risk. Remedial works can also be recommended in the database that stores the risk assessments.

SSE calculate a value for criticality, which is defined as follows:

$$\text{Criticality} = \text{probability} \times \text{severity} \times \text{likelihood},$$

Where: probability is ‘probability of failure’;
severity is ‘severity of consequence’; and
likelihood is ‘likelihood of detection’.

It is important to note that the likelihood of detection relates to the probability that the failure will be detected before it occurs, but it also takes into account the fact that some failures may not be detected even after they have taken place. This suggests that some elements of the system can actually be allowed to fail. For example, if one considers the systems used for conveying water, such as aqueducts, some are clearly of far greater importance than others. An aqueduct that brings a small amount of water into a reservoir that feeds into a small power station at the bottom of a cascade of dams, is clearly less critical to the continued profitability of the company than an aqueduct that feeds water into a reservoir at the top of a cascade of reservoirs (which would result in that same volume of water generating electricity at several power stations).

The probability of detection (either prior or after failure) is ranked as “low”, “medium” or “high”, however the final scores used in the assessment of the criticality of the asset (probability of failure, severity of consequence, and likelihood of detection) are all scored on a scale of 1 to 5. The company has developed matrices to help ensure consistent ratings are given to these three factors. For example, the severity of consequence score is taken from a matrix that includes the PAR (number of people at risk) as one of the factors.

Once the criticality score has been determined for the asset in its current condition, another score is calculated for what the situation would be if remedial action (such as maintenance) were to be taken. The difference between the two numbers also aids in prioritising work.

The criticality scores are not an end in themselves. They are ‘ball park’ figures, which are used to point up the main areas of concern. Engineering judgement and management skill are used to draw up a finalised work schedule. Thus, if, for example, a valve at a certain dam is found to have the third highest criticality score (i.e. is priority three), but another valve of the same type and at the same location is only priority twenty-seven, it would be sensible to maintain both at the same time, even though the component with the lower priority effectively “skips the queue”.

Generally the final timing of the work will be determined by other factors than the risk assessment priority ranking. The most obvious of these is funding, since it is not always possible to support all the most critical projects in the same financial period. Other concerns, such as resource availability and weather conditions will also have a bearing on the timing of the work. The final schedule is thus often drawn up following negotiation between people at different levels within the company who have different perspectives on the decision.

4.5.4 UK CIRIA Methodology

The CIRIA Research Project 568, “Risk and Reservoirs” was aimed at producing a document for guidance on risk management for UK reservoirs. The report has drawn on the work of SSE as well as the Canadian approach and is now seen as the industry best practice within the UK. The work was initially hampered by a lack of data, but benefited from the comprehensive records held by BRE and others (Tedd *et al*, 2000; Hughes *et al*, 2000 a/b). The work was carried out with extensive consultation with various stakeholders, including engineering practitioners, panel engineers and insurers.

The approach is intended as a report for guidance, to be applied where risk assessment is “appropriate”, not in every circumstance (Hughes *et al*, 2000a). It is based on historical data for the UK, which varies from the rest of the world having a stock of dams that are mainly embankment dams over one-hundred years old. The approach differs from the Reservoir Act (1975) in that, instead of applying to reservoirs according to capacity (Charles, 2002a), it acknowledges that risk does not depend wholly on capacity, but other characteristics, such as the shape of the catchment, the use of downstream land, the seismicity and geology of the region and the design of the dam structure itself. This approach is therefore important because the databases of failure records are, by their nature, a lower bound of risk (as some failures may not be recorded) as well as the fact that this approach could be applied to the large number of small dams that are not covered by the ICOLD guide. This is particularly important, as smaller dams may be older, privately-owned, badly engineered and poorly monitored.

The CIRIA methodology adopts the “three factor” approach of the SSE criticality score and uses historical case studies to provide the practitioner with examples of failure mechanisms to consider for each type of dam (classified according to height, age and material of construction). The methodology includes the use of a FMECA (Failure Modes, Effects and Criticality Analysis) and LCI (Location, Cause, Indicator) diagrams.

The CIRIA approach comprises three stages (Hughes *et al*, 2000 a/b; Tarrant *et al*, 2002). These are outlined in the following paragraphs.

Stage 1: Impact Assessment

The CIRIA report divides the impact assessment into five steps (below). The overall aim is to assess the consequences of a possible dam failure in order to gain an “impact score” which

can be used to categorise the dam and prioritise further studies (amongst a portfolio of dams). The steps are (Hughes *et al*, 2000 a/b; Tarrant *et al*, 2002):

1. Collecting reservoir information and carrying out a site visit;
2. Estimating peak discharge and flood hydrograph for the dam;
3. Calculating potential flood levels (through dividing downstream valley into regions and zones);
4. Calculating potential reservoir impact (low, medium, high); and
5. Combining the scores and identification of likely consequences of dam failure.

Stage 2: FMECA Selection

The impact score calculated in the first stage is used to determine the extent of further assessments. Dams with a low impact score need not have any more risk assessment carried out. A moderate score results in a Level I assessment (considering only complete failure of the dam), while a high impact score leads to a Level II assessment. This considers partial failure modes, such as gate failure or one or more blocks being displaced, as well as complete failure of the dam body.

Stage 3: FMECA Risk Assessment

The Failure Modes and Effect Criticality Assessment results in ranking and prioritisation of a number of dams, rather than an “absolute” score for each dam. FMECA is described in more detail in Chapter 5, but the perceived advantage of the approach for the dam sector is that:

“FMECA offers a balance between the two extremes of relying solely on engineering judgement and the rigour (and expense) [and potential impossibility] of fully probabilistic analysis. It also provides the flexibility to deal with varying levels of knowledge of the performance and reliability of different dam components [and failure modes]. The approach does not require specific probabilities to be attributed to the failure of a specific component. Instead, it requires a qualitative assessment as to the probability, likelihood of detection and consequences of failure”

(Hughes *et al*, 2000a)

The third stage of the assessment uses five key tools:

1. LCI diagrams;
2. Consequence, likelihood and confidence scores;
3. Criticality and risk scores;
4. Ranking and prioritisation; and
5. Presentation techniques.

The LCI (Location, Cause, Indicator) diagrams provided in the CIRIA documentation are tree-like structures which first identify the area of the system where a failure might occur.

then suggesting causes of the failure along with signs that might be present that would indicate that a risk of the particular failure is developing. An example is given in Figure 4.3, below.

The colours given for Consequence, Likelihood and Confidence are based on historical records. The criticality scores are calculated in a table from the scoring attributed in the elements of the LCI Tree, where:

$$\text{Criticality Score} = \text{Consequence} * \text{Likelihood} * \text{Confidence}.$$

The justification for each score is also recorded and will be based on answers to the questions given in Table 4.3.

| Table 4.3: Determining Consequence, Likelihood and Confidence scores | | |
|--|--|--|
| Score Element | Question | Score |
| Consequence | How directly is failure of a given element related to failure of the dam? | 1 = low (failure of the element is unlikely to lead to dam failure) 5 = high (failure of the element is highly likely to lead to dam failure) |
| Likelihood | What is the likelihood of the failure of this particular element? | 1 = low (there is a low probability of the element failing) 5 = high (there is a high probability of the element failing) |
| Confidence | What is the assessor's confidence in the reliability of the values assigned to these consequence and likelihood scores | 1 = low (the assessor has a low confidence in the predictions) 5 = high (the assessor is very confident in the predictions) |

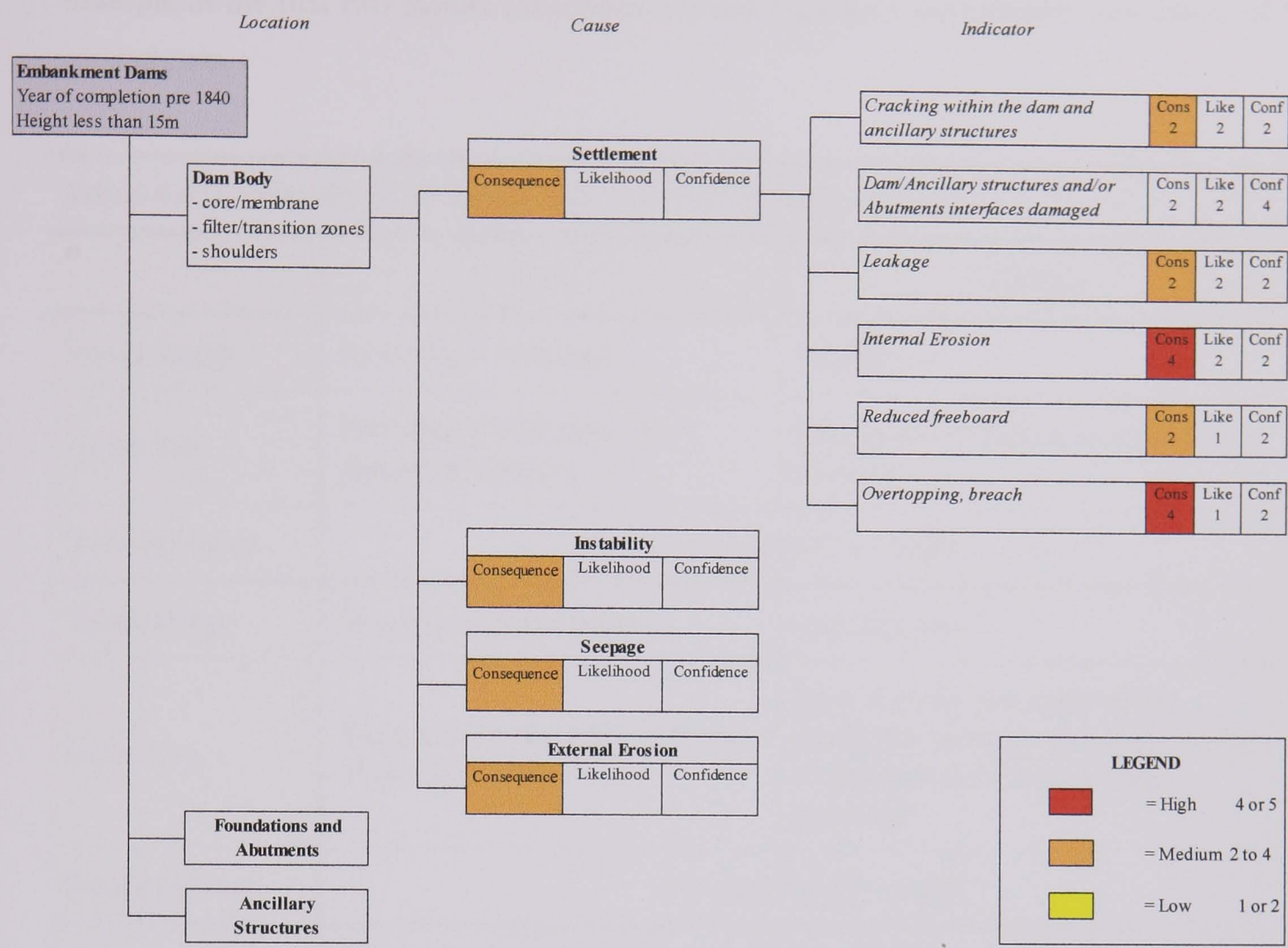


Figure 4.1: Extract from LCI Tree 7 – from the CIRIA Methodology (Hughes *et al*, 2000)

To demonstrate the extent to which the CIRIA approach has been influenced by the earlier work of Scottish and Southern Energy, the three elements of the Criticality Score are given in Table 4.4.

The “probability of failure” or “likelihood” and the “consequence” terms are easy to understand and draw directly from the long history of FMEA-related methodologies (see Chapter 5), although the dual use of the term “likelihood” can be confusing. The greater the probability (of failure) and the larger the consequence (hazard), the bigger the score will be. The ‘confidence’ term is more complicated. The higher the value, the less ‘confidence’ the assessor has. Therefore, the most risky assets are those with scores up in towards 125 (5*5*5), whereas a score of 1 would be of negligible risk.

Unfortunately, as Tarrant, Ackers and Graham-Smith (2002) have found, and as Hughes *et al* (2000b) suggested might be the case, the confidence score can cause some problems. For example, it could be the case that the assessor is very confident that failure of an element is very likely and would have disastrous consequences. This would result in a score of only 25, due to a confidence score of 1. Therefore, best practice at present is to first consider the

multiple of the first two factors (likelihood and consequence) and consider confidence on a second pass.

Table 4.4: Criticality score in the SSE and CIRIA Methodology

| | SSE | CIRIA |
|---------------|--|--|
| Terminology | Probability of failure | Likelihood |
| Definition | Probability of failure of a particular element | Likelihood of failure of a particular element |
| Scoring Range | 1 (= low) to 5 (= high) | |
| Terminology | Severity of consequence | Consequence |
| Definition | What will the knock on effects of this failure be? | How directly is failure of the particular element related to failure of the dam (or a higher level process)? |
| Scoring Range | 1 (= low) to 5 (= high) | |
| Terminology | Likelihood of detection | Confidence |
| Definition | How likely is it that the hazard will be detected before, during, or even after failure? | How confident is the assessor with the judgments of the consequence and likelihood of failure? |
| Scoring Range | 1 (= high) to 5 (= low) | |

The confidence factor, as defined by the CIRIA report, is intended to take into account not only the likelihood of detection, as in the case of the SSE version, but also:

- the completeness of the evidence available (e.g. whether there are any written records of the history of the dam, quality of construction, maintenance and repair workmanship
- the quality of the evidence considered (e.g. accuracy of as-built drawings, experience of inspector etc);
- the dependability of the mitigating factors (e.g. does maintenance take place as it should); and
- the uncertainty intrinsic in the assessment (e.g. where it is difficult to inspect visually, or where interactions are difficult to assess).

In addition to the criticality score, the methodology suggest a ‘risk score’, defined as:

$$\text{Risk score} = \text{Reservoir impact score} * \text{Criticality score}$$

The impact score relates to the impact that a dam breach would have on downstream communities. It is calculated for seven different land use types and takes into account an estimation of the PAR (People or Persons at Risk). This is an important distinction from the SSE methodology where this impact is put into the consequence score. The reason for this difference is that ‘consequence’ can be measured in two ways. One is to consider the consequence of failure of an element on the integrity of the dam, the other to consider the consequence of failure (or breach) of the dam on human life (and property). This brings in to sharp focus the perennial question that faces experts in this field. Is the aim of condition monitoring and asset management of the dam to preserve the dam structure in the event of an extreme event, or is it to prevent loss of life (even if this means that the structure itself should be forfeited)? Note that the criticality score combines consideration of risk to the dam structure and to human life, and therefore manages to resolve this debate to an extent.

4.5.5 Canadian Best Practice

One of the countries leading the development of best practice in Dam Safety is Canada. Their approach is largely driven by the advances being made by BC Hydro, which is the third largest electricity utility in that country and has developed an internationally recognised Dam Safety Programme. The approach comprises eight key components:

1. Performance Monitoring;
2. Dam Safety Reviews;
3. Deficiency Investigations (DI);
4. Risk Assessment;
5. Seismic Studies;
6. Precipitation and Flood Studies;
7. Emergency Preparedness; and
8. Training.

Performance Monitoring is carried out in the same way as in the UK through the use of instrumentation, assessments, visual inspections and surveys. The Dam Safety Reviews are undertaken every five to ten years and are similar in scope to the UK Inspecting Engineers report. Deficiency Investigations are studies into potential deficiencies, the consequences of failure and methods for remedying the deficiency. Although the standards are slightly different, the approach to Precipitation and Flood Studies is similar, with attention paid to:

climate data collection; inundation studies; run-off models and flood forecasting (including the use of a PMF approach).

BC Hydro's approach to Seismic Studies is more formal than what currently takes place in the UK. In addition to the use of seismic hazard studies and stability analysis; paleoseismic investigations and ground response studies are also undertaken. The Canadian approach to Emergency Preparedness is markedly different to the UK. Once failure scenarios have been identified (triggered by environmental incidents, accidents, earthquakes or other disasters) plans are made. These are "continuously updated internally and externally with the plans of affected communities and government agencies" (Hartford *et al*, 2000). This reflects a different political climate and societal familiarity with risk to that of the UK.

The BCHydro experience with assessing dam safety through quantitative and qualitative risk assessments has provided a number of key lessons. The company's attempts to apply risk assessment techniques in a quantitative manner have not proved as simple as they had assumed. In particular:

"Failure Mode and Effects Analysis, Event Tree Analysis and Fault Tree Analysis are conceptually appealing, [but] much more difficult to perform than expected [due to the difficulty in determining] the interaction between components [and] the empirical nature of dam design may be a contributing factor".

(Hartford *et al*, 2000)

The Canadian approach, as captured in that country's Dam Risk Management Guide (Hartford, 20003) is described graphically in Figures 4.2, which demonstrates the way in which Risk Assessment fits within a wider Dam Risk Management Process.

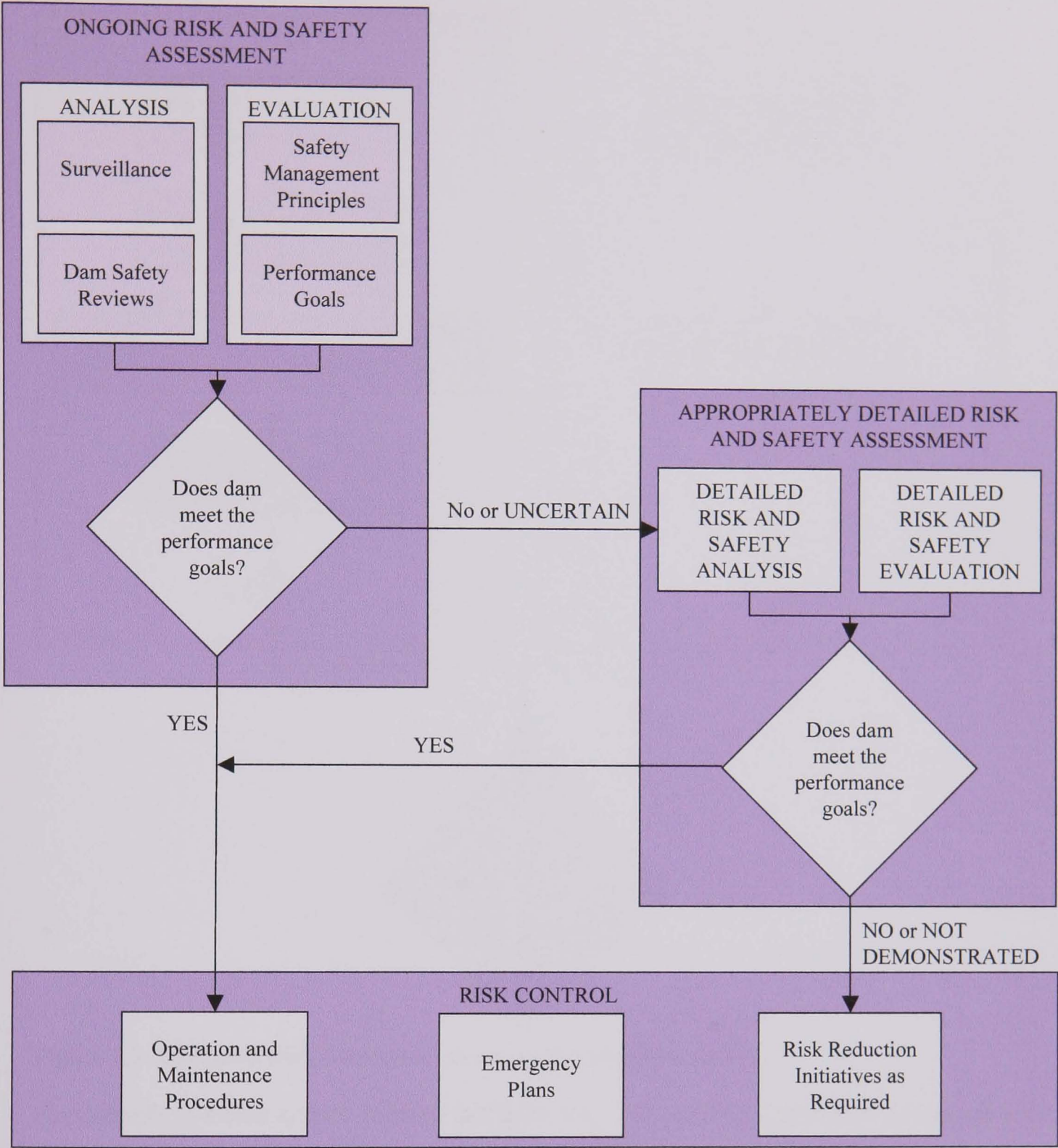


Figure 4.2: Canadian Risk Management Process for Dams (Hartford, 2003)

Figure 4.3 highlights the actual methods that are used to carry out the Risk Assessment. The risk assessment is carried out for the “Dam System”, which is defined as

“the bounded physical entity that encompasses the dam and reservoir, the area downstream of the dam and all entities impacted either directly or indirectly by failure of the dam and/or appurtenant structures”

(Hartford, 2003)

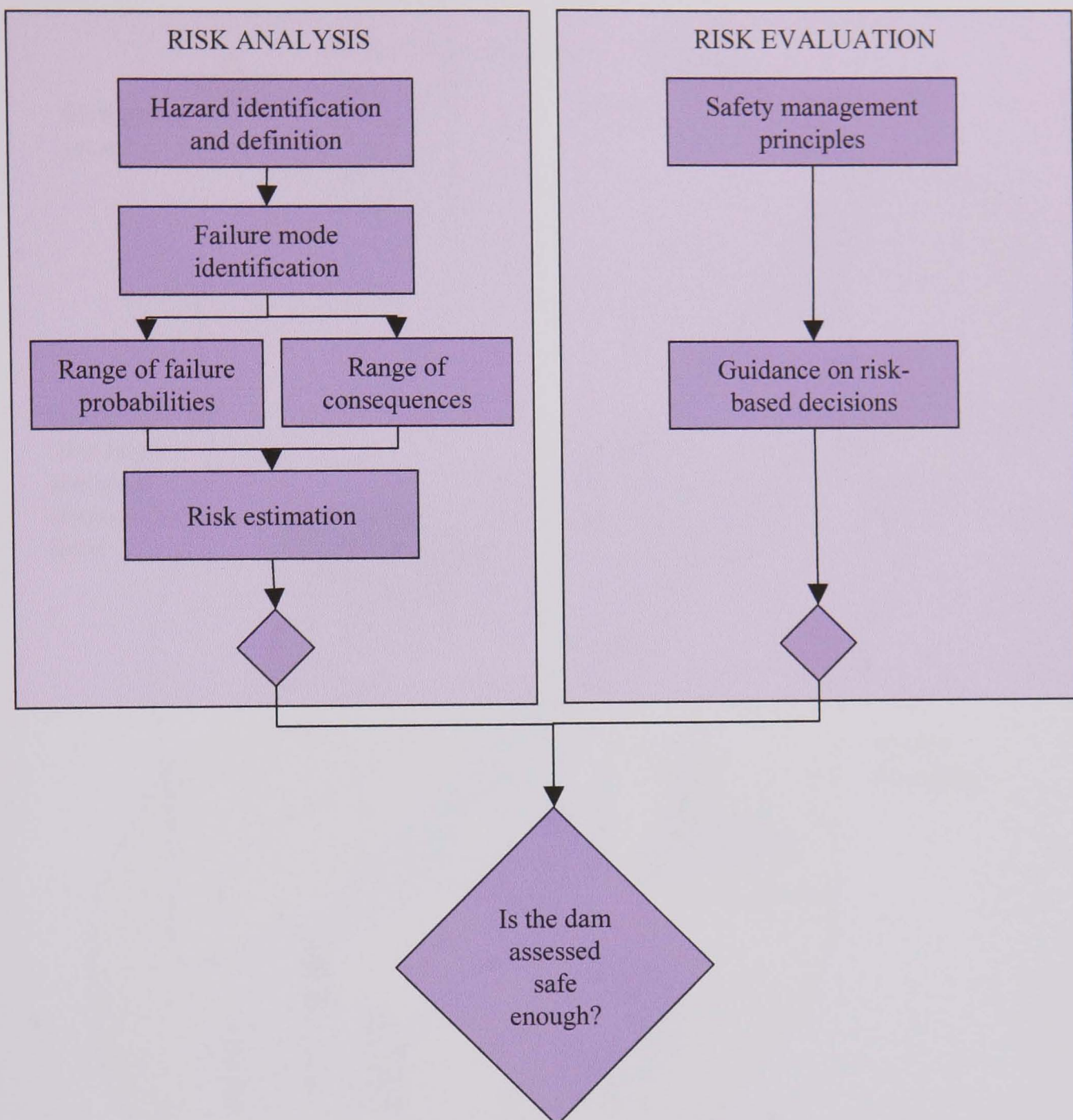


Figure 4.3: Canadian Risk Assessment Framework (Hartford, 2003)

An example of a dam system is given in Figure 4.4. The system is defined as a physical area and all flows into the system (e.g. water) and influences on the system (e.g. seismic shaking from a distant source) should be identified. The area of influence may include the entire watershed, depending on the situation.

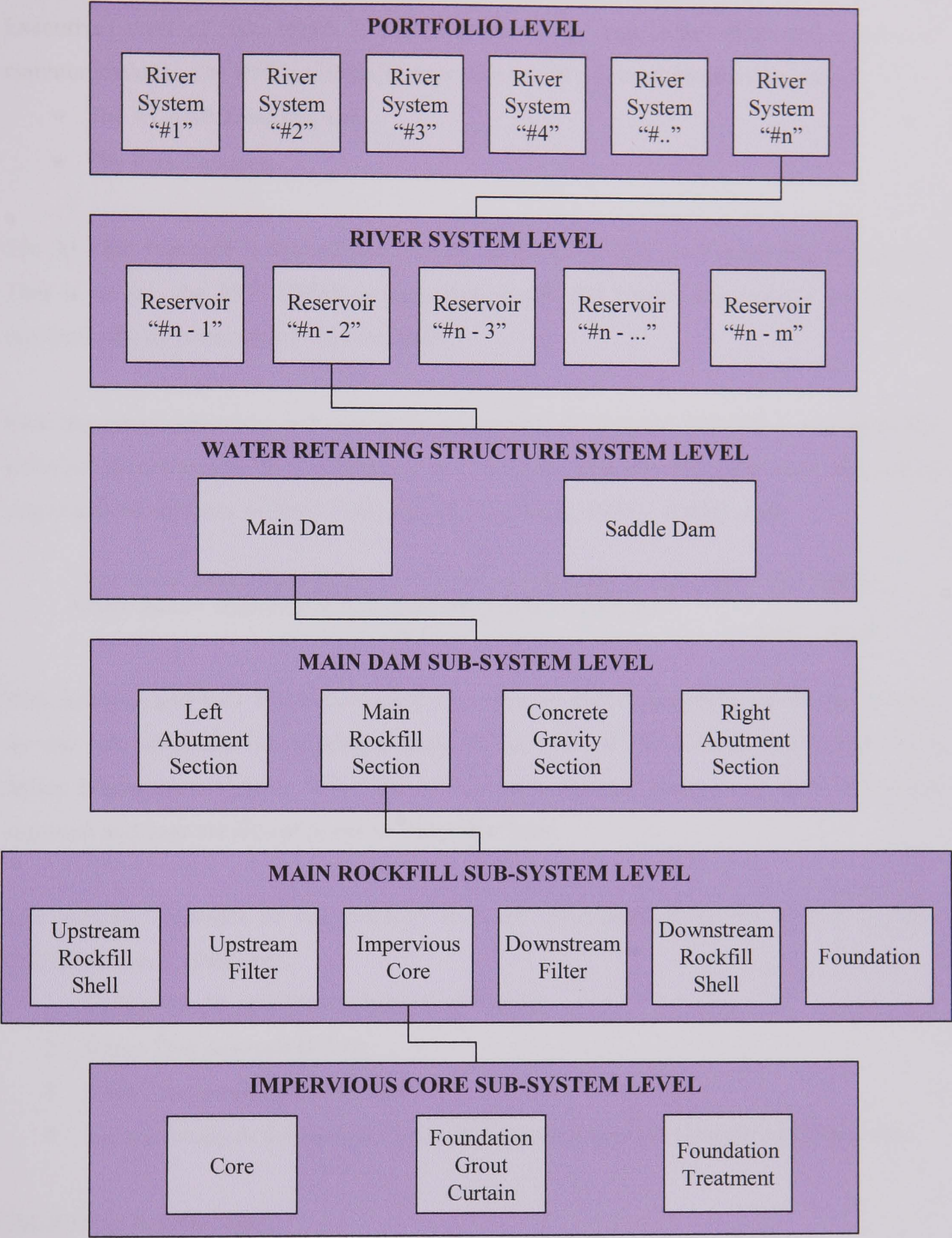


Figure 4.5: System Component Diagram (Hartford, 2003)

4.5.6 The ICOLD Methodology

It is not surprising, given that one of the key authors of the ICOLD Bulletin on Risk Assessment (McDonald *et al*, 2000) is Dr Des Hartford of BC Hydro, that the approach draws heavily on both the Canadian best practice and the HSE (the UK Health and Safety

Executive) view of risk, which is highly respected by that expert (Hartford – personal communication). The HSE’s (2002a/b) approach to risk can be summarised as being:

- The ALARP Principle; and
- The Risk Equation.

The ALARP Principle is that all risks should be made As Low As Reasonably Practicable. That is to say, the HSE (2000) accepts that in the real world, risk cannot (practically, economically or sustainably) be eliminated.

Risk has many definitions but that given in the British Standard BS4778 is known as the technical definition and “is a measure of the likelihood of a specific undesired event and its unwanted consequence or loss” (Francis and Fairclough, 1993). It states that:

“Risk is the combination of the probability, or frequency of occurrence of a defined hazard and the magnitude of the consequences of the occurrence”

(BSI, 1991a)

Risk Analysis and Risk Evaluation together provide a Risk Assessment, which can be used for the risk-based decision-making process at the heart of the ICOLD approach to Dam Safety Management (Figure 4.6). The ICOLD methodology draws on the HSE’s ALARP approach and uses the idea of limits of “tolerable” risk.

The principle methods of risk analysis that are recommended in the ICOLD bulletin (McDonald *et al*, 2000) are:

1. Failure Modes and Effects Analysis (FMEA);
2. Event Tree Analysis (ETA);
3. Fault Tree Analysis (FTA); and
4. Various methods for estimating dam failure consequences (inundation studies etc.).

The ICOLD bulletin states:

“The principal role of the dam engineering community in dam safety risk assessment is to lay out the facts, clearly stating what is known and not known. Those with a duty to control risk (the owners, or where they exist, regulators, and the political system) decide what to do.”

(McDonald *et al*, 2000)

Unfortunately, the format of the ICOLD method, shown graphically in Figure 4.7, as with the CIRIA and Canadian methodologies may fail “clearly [to] state what is known and not known”. The attempt to assign probabilities of failure and to list *all* possible hazards, is fraught with uncertainty. There is clearly a need (acknowledged by Des Hartford in person

during a discussion with the author in September 2002) to have some decision-making framework that allows “those with a duty to control risk” who may not have a background in engineering, mathematics, or statistics, to communicate with one another and “decide what to do”.

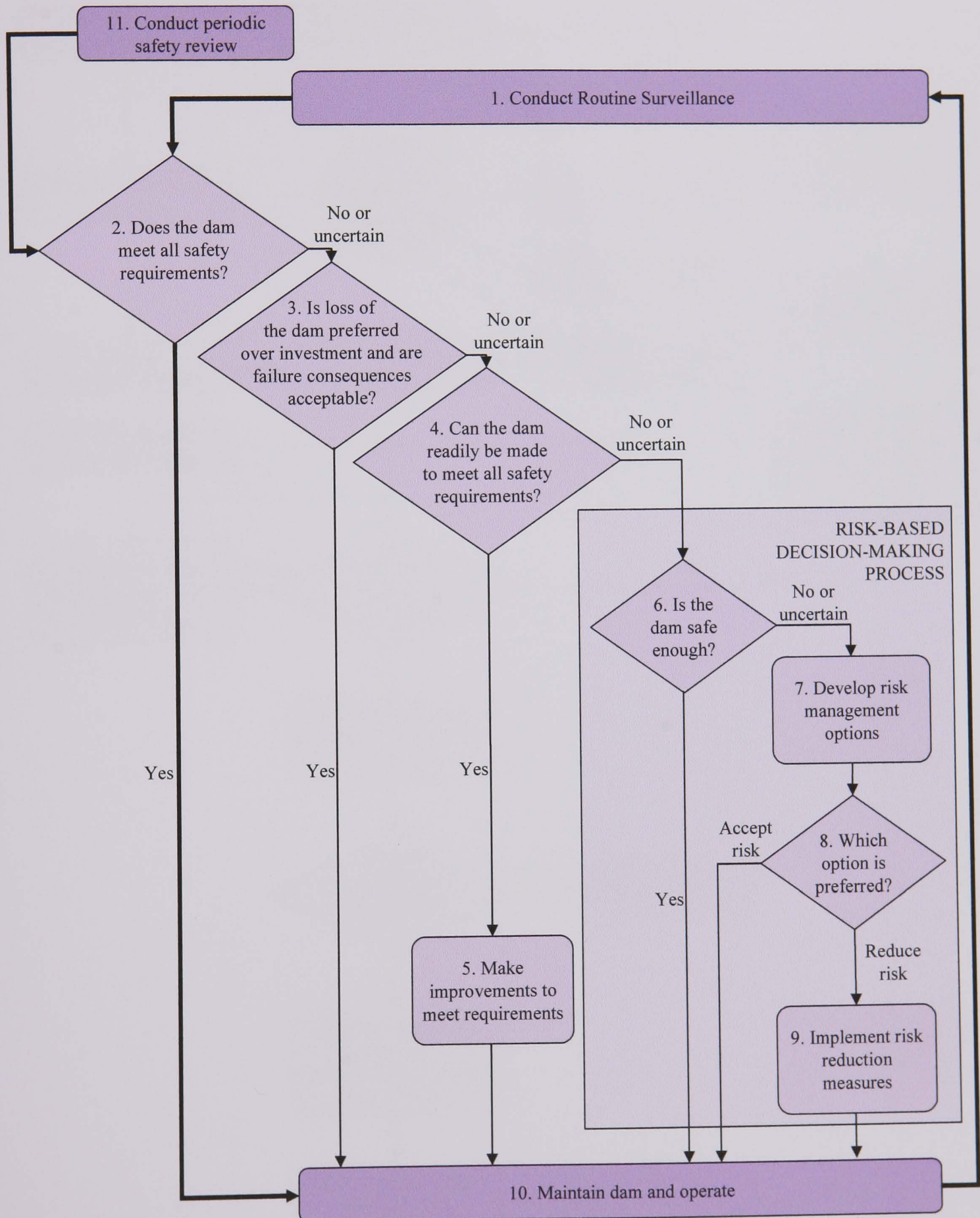


Figure 4.6: Dam Safety Management (ICOLD, 2000)

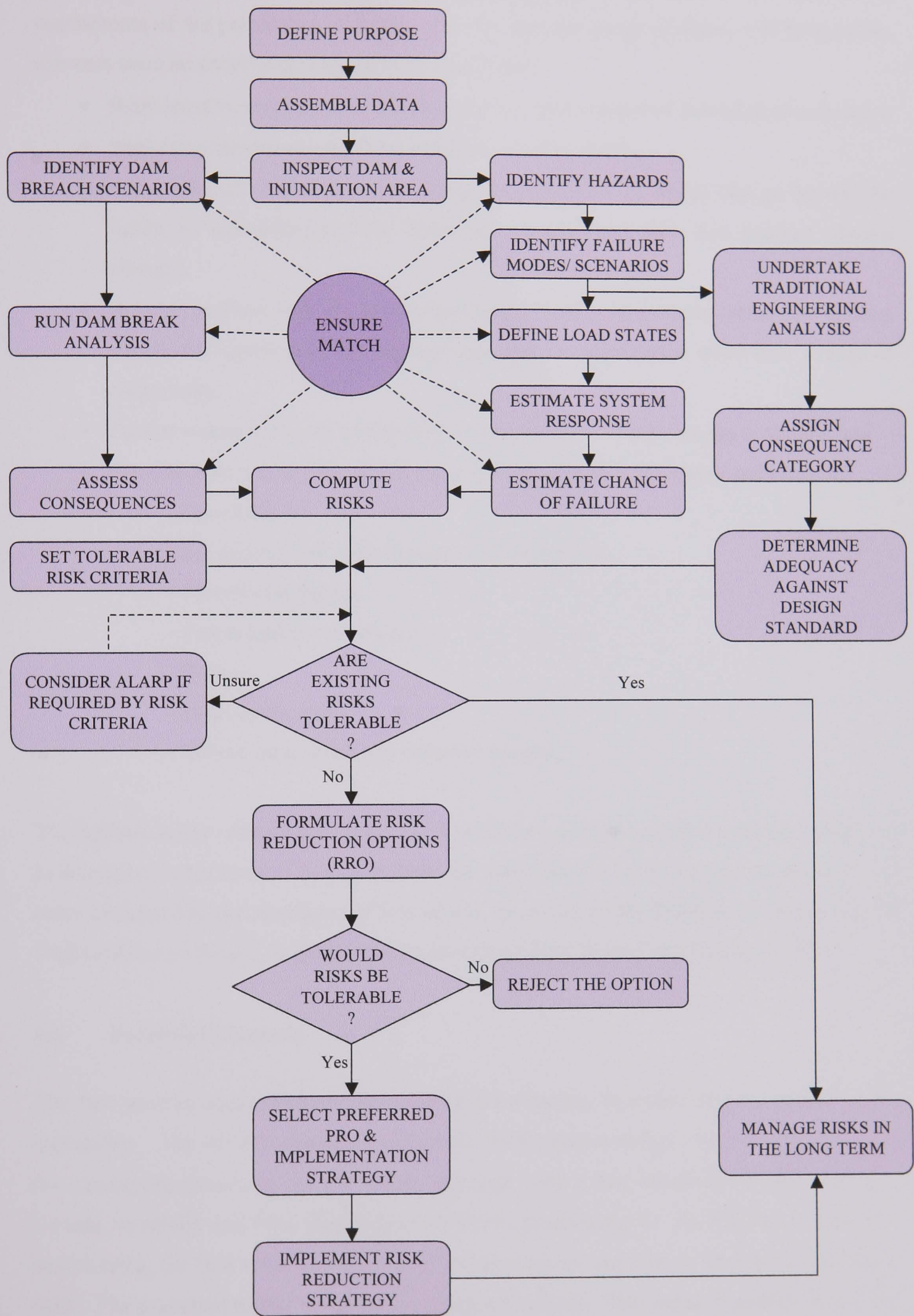


Figure 4.7: ICOLD Risk Analysis, Assessment and Control for a Dam (ICOLD, 2000)

The ICOLD Bulletin (McDonald *et al*, 2000) acknowledge that before quantitative assessments of the probability of failure (P_f) of a dam (or group of dams) will be possible, research must be undertaken into the following fields:

- Retrospective methods for identifying failure probabilities of dams that already exist;
- Improving databases with finer and more relevant details;
- More accurate methods for estimating the probability of floods that go beyond the limits of extrapolation from historical records (and take into account climate change);
- A better methodology for estimating the probability of extreme earthquake loading events, the significance of the magnitude, and the acceleration effect over a range of magnitudes;
- Further research into the probability of liquefaction and failures due to sliding; and
- Development and testing of analytical models to predict the timing and effect of:
 - Dam failure;
 - Liquefaction of embankments or foundations;
 - Flood overtopping;
 - Embankment saturation;
 - Piping;
 - High uplift; and
 - Waves created through reservoir slippage.

The Bulletin acknowledges that, even if a P_f could be calculated, further research is required to determine “what level of risk from dams the community would regard as acceptable”. In order to determine the likelihood of loss of life, improved methodologies for estimating the PAR (number of People At Risk) must be developed (McClelland and Bowles, 1999).

4.6 Potential Hazards

The best practice methodologies for ensuring Dam Safety, described above, are risk-based approaches. The ICOLD Bulletin (McDonald, 2000) acknowledges that this appears to be the emerging consensus for the sector, although only a few countries (notably the UK, Canada, Australia and New Zealand) are actively progressing it. As Figures 4.6 and 4.7 demonstrate, the first stage in these risk-based approaches must be to analyse and evaluate risks. The precursor to this is to identify potential hazards. This subsection describes some of the hazards that are faced by dam owners, which are directly related to dam safety.

The ICOLD Bulletin (McDonald *et al*, 2000) suggests that hazards faced by dams can be grouped into four broad categories, which are:

1. Hazards due to natural conditions (normal loads, earthquakes, floods, debris, wind, ice, etc.);
2. Operational hazards (spillway reliability, operator error, etc.);
3. Internal hazards (ageing, alkali-aggregate reaction, internal erosion (could be triggered by natural hazards), metal fatigue, etc); and
4. Social hazards (war, vandalism, sabotage, etc.).

4.6.1 *Natural hazards*

Normal Loads

The category of “normal loads” is an interesting one, because there are several stages in the life of a dam, which could be considered “normal” but never the less place varying stresses on the structure. These phases include:

- Construction
- First-filling
- Normal operation
- Slow drawdown
- Rapid drawdown

While concrete and masonry dams do experience changes in forces during their life, which could result in sliding or overturning, it is embankment dams that generally require special consideration with regard to varying pressures and forces on the structure (Tedd *et al*, 2002). In addition, while there can be some uncertainty with regard to the exact materials used within a concrete dam, the geotechnical parameters of an embankment dam can be still harder to control and understand (Craig, 1995). In all dam types the integrity of the seal between the dam and the valley sides and base can be critical in determining the strength of the structure, as leakage here can be critical.

Best practice in establishing the “normal” forces on dam structures involves the use of modern soil mechanics, and the application of finite element analysis to investigate worst realistic loading conditions and the stresses that would be experienced by the structure if a crack or other fault were present.

Earthquakes

While the UK is not generally considered to be an area where earthquakes cause destruction, the consequences of a failure due to seismic activity would be large, due to the potential rapid collapse of a dam. Partly as ethical action and risk minimisation, and partly due to pressure from special interest groups and increasingly vocal stakeholders, dam owners are increasingly investing in seismic safety assessments of dams and appurtenant works in areas of low to moderate seismicity (Taylor *et al*, 2000; Sanchez-Silva, 1995; Sanchez-Silva *et al*, 1995,1996).

However, a recent survey of world practice on the selection of the Maximum Design Earthquake, has revealed that there is no consistency in terminology and, more worryingly:

There seems to be no widely established authoritative good practice anywhere. Here the term 'authoritative good practice' refers to practices where there is a consensus between regulators, technical experts, owners and safety experts as to what is appropriate.

(Fan and Imrie, 2000)

The survey summary document reiterates the point that, while there is an overwhelming sense among all those associated with the dam sector, that loss of life is unacceptable, due to the unpredictable nature of these potentially devastating natural events, there can never be “absolute” safety for dams.

It is interesting to note the rapid progression that has taken place in the UK from raising the question of whether or not reservoir control systems and structures should be designed to withstand the dynamic effects of earthquakes (Ballard and Lewin, 1998) to beginning to carry out seismic assessments.

SSE exceeds current best practice, as it is perceived in the UK, by following the guidance published in the BRE Guide (Charles *et al*, 1991) and actively carrying out seismic assessment (Dempster *et al*, 2002). While the BRE Guide has been controversial (Scott and Bommer, 2002) it has the advantage of being a pragmatic tool since it uses a workable method of placing dams into categories according to their likely level of risk. The assessment is based on four classification factors: capacity of the reservoir, height of the dam, evacuation requirements and potential damage downstream. In line with UK practice (Fan and Imrie, 2000), the Peak Ground Acceleration (PGA) is then applied for the Safety Evaluation Earthquake (SEE). The dam category and height are used to provide guidance to the level of seismic safety evaluation that is required. The dam type is also considered in two broad categories, “embankment” and “concrete and masonry”. The Guide does not give

worked examples of the design of dams under seismic load, leaving the reader to study the appropriate parameters and other details using textbook methods for stability design.

In the case of SSE, the Guide suggests that most of the dams in the east of Scotland are located in Zone C (few or no recorded earthquakes, but some events possible). However, many of the dams are located in Zones B (medium activity) and A (relatively high activity). The company supplements this information by maintaining a graphical record of earthquake activity as it is reported. While there are some (Scott and Bommer, 2002) who hold that the current Guide (Charles *et al*, 1991) is too conservative, one of their justifications for this belief is the fact that no “well built” embankment dam has ever failed due to seismic action (with the exception of the Lower San Fernando dam in California which failed during an earthquake due to the liquefaction of the saturated cohesionless hydraulic fill). Nonetheless, even though Scott and Bommer confidently assert that the UK is “blessed with a stock of intrinsically seismically robust structures” and McClelland and Bowles (1999) have found “no well-documented examples of flood-related life loss following an earthquake”, SSE are wise to continue in their course of study and remain at the leading edge of seismic knowledge because most of their dam stock are masonry or concrete dams, which may be more prone to earthquake failure than the embankment dams that form the majority of the UK’s “robust stock”.

In line with the thinking of leading experts in the field (Ballard and Lewin, 1998; Daniell and Taylor, 2002; Rigby *et al*, 2002) SSE not only continue to assess the seismic vulnerability of their dam structures through new and innovative methodologies (Dempster *et al*, 2002) but also take care to assess the appurtenant works (for which less guidance is available), because they understand the important role that these play in maintaining the structural integrity of the reservoir containment system (Sandilands *et al*, 1998).

Debris

There are two ways in which debris can cause a hazard to a dam; the first is where the debris triggers a second failure mechanism; the second is when the debris is the result of some other event.

In the first case, debris (from trees near the reservoir, for example) can become an “incubating precondition for failure” (Blockley and Godfrey, 2000). This could occur if the debris were to become trapped in the spillway, which would result in reduced capacity and could lead to overtopping of the spillway during a high rainfall event. Similarly, debris in the gates or valves could prevent proper operation when required. Best practice for

preventing these problems includes fitting and maintaining screens to prevent the debris entering the dam structure. This is not only critical to the integrity of the dam itself, but also prevents damage to turbines in the power station.

Debris can also form a secondary hazard, following an earthquake, for example. Studies (e.g. Daniell and Taylor, 2002) have shown that debris, or even complete appurtenant structures (such as intake towers) can pose a threat to the main dam structure. An extreme example of debris threatening the safety of people downstream of the dam occurred in 1963 when a huge landslide behind the Vaiont dam in northern Italy took the lives of over 2,500 people when a wave of water and debris spilled over the dam and swept away a small town (Kirby, 2002).

Floods

Floods can be caused by extreme rainfall events and/or by melting snow. The failure of a dam to withstand a flood can have a number of effects, including:

- Damage to, or loss of, the dam;
- Loss of life below the dam; and
- Loss of confidence of the public.

In the case of a concrete or masonry dam, an event resulting in flooding and overtopping of the structure may not be devastating in terms of the integrity of the dam. Indeed, in some cases, overtopping may occur on a fairly regular basis (e.g. once a decade), and is permissible because downstream structures, such as the power station, are designed to withstand such an event. However, in the case of an embankment dam, or any dam above a sensitive downstream area, overtopping may not be permissible.

Even though flooding would still occur if the dam were not present, the general public tend to perceive such an event as being a failure of the dam owner, even though, in truth, the reservoir can only ever attenuate a flood peak (depending on the spare capacity in the reservoir and the intensity and duration of the rainfall). Nonetheless, those living downstream of a dam assume that it will protect them, regardless of the extreme nature of the event. An interesting dilemma for the dam owner in the case of flooding must be to balance the needs of those living below the dam as well as those who could be flooded upstream if the reservoir bursts its banks.

A difficult balancing act must be carried out to maintain the reservoir at sufficiently high levels as to maximise operational efficiency (of the generating sets), while at the same time

avoiding spill, which can be both bad for the dam structure as well as a waste of water that could be converted into electrical energy. Best practice organisations, such as SSE have become expert at balancing these conflicting demands. They will have established maximum and minimum reservoir levels, based on historical records, as well as modern techniques for assisting in predicting future rainfall. For example, the SSE control room has real-time satellite images of the current and likely future weather conditions that would affect their catchments.

There is some debate in the dam sector as to whether or not it is advisable for owners to carry out inundation studies. Some believe that doing so opens the industry up to litigation and liability in the case of an incident. Nonetheless, accepted best practice is to take the measures necessary to identify priorities for investment. Therefore, flood and dam break studies give an indication of the consequences that are possible and assist those responsible for the dam by providing further information regarding the way in which spending should be prioritised to ensure the maximum reduction in risk for the investment available. These inundation studies are thus used to inform risk assessments such as those outlined in the methodologies above (Tarrant *et al*, 2002; Hughes *et al*, 2000a/b).

As has been noted earlier in this report, one of the ways in which it is possible to determine the number of PAR from a reservoir is to produce inundation maps. These are useful for two reasons. Firstly, they allow the reservoir and dam owner to produce contingency plans (e.g. for alerting neighbours and working with the emergency services to ensure the safe evacuation of people in the area). Secondly, they assist in the prioritisation of work by indicating which dams could prove the greatest hazard in the event of a PMF or breach incident. The SSE's policy document on reservoir inundation studies (1999) describes the need for inundation studies as follows:

"The purpose of inundation mapping studies is not to carry out a liability exercise nor simply to comply with the above general requirements <for Health and Safety at Work Act 1974 and Control of Major Accident Hazards, EEC Directive, 1984> but to form part of HE's <now SSE> ongoing dam safety and asset management programme."
(SSE, 1999)

The company are not required by law to carry out these studies either under the Reservoirs Act 1975 or the EEC Directive, 1984 "Control of Major Accident Hazards" (CIMAH) which applies to major industrial plants. The Health and Safety at Work Act 1974 has some bearing on the preparation of inundation maps and overall duty of care obligations. The company has taken the view that best practice goes above and beyond that stipulated in the

relevant regulations. In the event of the very rare and extreme events that could occur, inundation studies would assist in controlling the way that situation would be managed.

Inundation studies are carried out using a computational model to simulate the propagation of a flood wave. This is usually only done for full or partial dam failure (Hughes *et al.* 2000), but best practice companies such as SSE also do a study for the effect of a PMF (probable maximum flood) situation. These studies also allow the company to check the category of their dams (A, B etc.) by ensuring that they have accurate figures for the number of people that might be killed, in order to assess the hazard using the ICE guide “Floods and Reservoir Safety” (1996).

The current confusion between the FSR and FEH, described in Chapter 2 and the apparent trends in global warming (Vaughan *et al.*, 2002a/b; MacDonald and McNally, 1998; MacDonald and Scott, 2000) means that there is a great deal of confusion and debate regarding spillway design and related capacity issues. This must be resolved to ensure that best practice continues while risk are made as low as *reasonably practicable*, without becoming prohibitively expensive such that dam owners are no longer able to make sufficient profit to justify their existence. After all, if a dam becomes economically unsustainable there is then the life cost of maintaining it *in situ* to maintain the ecological *status quo* of the reservoir, or else, decommissioning the dam. This last option is no small feat as it would be likely to involve the relocation of people living in the downstream catchment area of the original river.

Other extreme weather events

In addition to high rainfall events, snow melt can lead to flooding. Extreme wind conditions can lead to water being blown onto or over a dam. This phenomenon is due to lack of freeboard provided by the wave wall and can lead to overtopping, which, particularly for embankment dams, can have disastrous consequences. Current best practice for the provision of wave wall is to follow the guidance given in the “Guide to Floods and Reservoir Safety” (ICE, 1996) and the “Flood Studies Report” (Natural Environment Research Council, 1975) to ensure, in a similar way to extreme rainfall events, that the correct return period of the maximum windspeed is selected (Dempster and Lannen, 2002).

Extremely cold weather can be devastating in all types of dams, with freeze-thaw cycles resulting in internal stresses that can cause failure of a clay core, or, in the case of concrete dams, through expansion of water in the pores, lead to pieces of concrete breaking away from the structure. Three dam types are particularly vulnerable: 1) older dams, constructed

of more porous, low quality concrete and before the advent of air-entraining agents; 2) dams subject to frequent freeze-thaw cycles and 3) dams with short flow paths which are more likely to permit seepage to the downstream face. Best practice in all cases is to carry out frequent visual inspections, in line with (or exceeding) the local legislation as well as rehabilitation (see below).

Very hot weather can result in expansion of the materials in the dam, which leads to excessive external stresses, which in turn could result in cracking and partial or total failure of the dam. Again, best practice is to increase the amount of surveillance taking place during such periods.

4.6.2 Operational hazards

As stated earlier, the ResAct database (and Prescribed Form of Record) makes provision for recording any unusual events that occur to the dam system. In companies where best practice is used events with a human cause are extremely rare. However, there are those who argue that the traditional practice of having those who are responsible for a dam living in houses below the reservoir was an incentive to minimise human error. The key to minimising the chance that a human error could lead to the catastrophic failure of a system lies with appropriate training, providing incentives for good performance, planning back-up systems, and ensuring that one person is ultimately responsible for the safety of the asset (Deming, 1986), which is one reason why there remain those who support the 1975 Reservoir Act (see Chapter 2).

However, human errors are often the result of random variations in performance that are 'noise' between statistical limits (Wheeler, 1993; 2002). In order to reduce the risk of such errors occurring it is essential that the management systems are in place (Deming, 1986,1994). In order to make sure that the worker who will be carrying out the activity is aware of the risk (to themselves and the asset), they are required to produce risk assessments and give details of the measures that they will take to mitigate the risks.

There is also always a hazard posed by the operation of moving parts of the system. Gates and valves are high-risk elements (Lewin, 1998) and for this reason, SSE have taken care to manage the risk associated with these elements (Sandilands and Noble, 1998) through a bespoke application of the Failure Modes and Effect Criticality Analysis (FMECA). The main benefit of this type of risk assessment has been that it has provided a coherent methodology for prioritising refurbishment programmes (Sandilands and Noble, 1998).

Clearly, when a gate or valve is tested this will result in water being spilled (without generating electricity). Therefore, a balance must be struck between the frequency and extent to which the gate is opened and the resultant economic. When problems are found the whole gate may be protected by a temporary coffer dam so that it may be prepared. This clearly renders the gate inoperable and best practice organisations are therefore careful to schedule such works to times when extreme rainfall events are least likely. In addition, many organisations (Heitefuss and Kny, 2002) are now retrofitting emergency gates so that repairs can be made to the main gates without necessitating the complete draw-down of the reservoir that designers of the nineteenth century, not considering the resultant loss of income and potential severe ecological impact, had thought a viable option. Emergency gates, fitted by a diver, allow future underwater repairs to be undertaken in significantly greater safety and greater convenience.

Another hazard that can broadly be termed as “operational” is the one posed by the lack of historical records. In some cases original design drawings and “as-built” drawings may be conflicting or lost. This means that there may be some uncertainty with regard to the exact design used, the construction method, the materials within the dam, the temperature and other conditions during construction and other factors that could affect the behaviour of the structure. Some of these are “normal” and others “internal” hazards, but the problem is that without the supporting documentation, perhaps the greatest hazard is the fact that these other hazards are unknown and essentially unpredictable. This is why best practice organisations are increasingly focusing efforts on ensuring that drawings and other essential documentation are stored safely and in an accessible manner (Stewart, 2002).

4.6.3 *Internal hazards*

Internal hazards are a cause of great concern to those who are responsible for the safe operation of the UK’s dam stock. It is these “hidden” hazards that cause a great deal of uncertainty for the dam owners and panel engineers.

Dam ageing is an issue that leads to a large amount of uncertainty and more and more problems being identified. A chart of the number of problems as percentage of the number of dams in existence (Tedd *et al*, 2000) reveals that internal erosion has been the most common problem since the advent of modern dam building at the turn of the 19th century. The great expansion in dam-building that occurred in the 1950s means that a large stock of dams, mostly embankment dams (83% of the UK population) are now getting to an age where remedial works are required. The percentage of embankment dams known to have

problems associated with internal erosion (Skinner, 2000) has increased from around 5% between 1800 and 1950, to over 15% in the second half of the twentieth century.

In 1993 a European Working Group on Internal Erosion in Embankment Dams was formed to examine the hazard posed by internal erosion in existing dams (Charles, 2002). There are three recognised methods of best practice, all based on the Observation Method (Le Masurier, 2001). The first of these is the use of surveillance by operatives. This method is no longer so frequent with the advent of new technology and a trend towards no longer having a member of staff living on or near the dam. Instrumentation is the second method used, particularly where there are no visible symptoms but the dam is considered to be in a high hazard location, or when a change of state is taking place (such as first filling). The third method is the use of geophysics using techniques such as temperature measurements (Andrews and Dornstädter, 2000; Dutton, 2002), ground-probing radar and electrical resistivity.

At the present time, the risk of internal erosion remains unquantifiable and is a particular cause of concern for dam engineers because “Internal erosion is difficult to analyse and the continuing safety of embankment dams is dependent on an approach based on the observational method. However, internal erosion is a hidden phenomenon and until some feature such as a sinkhole appears at the surface of the soil, it is difficult to identify and investigate” (Charles, 2002). By which time, the dam may be on the point of collapse. Best practice organisations, identifying dams that are likely to suffer from internal erosion, perhaps due to the construction materials or practice used, or the design of the dam, take steps to remedy the problem. This can include, for example, “retro-fitting” internal drainage systems, a practice that is carried out in other dams, suffering from uplift, as well as in embankment dams where internal erosion may be exacerbated by pressure differentials (Bettzieche and Heitefuss, 2002).

Embankment dams are not unique in having potential internal hazards. In other dam types, internal hazards can occur due to design and construction details, such as the materials used and the quality of construction (including the porosity of the concrete or build-quality of masonry). There are some unusual dams, such as Allt na Lairige, a pre-stressed concrete dam owned by SSE, which have special considerations (such as occasional testing of the pre-stressed elements). Usually internal stresses within such structures are caused by environmental factors (see above), age, poor design (resulting in alkali-aggregate reaction or metal fatigue) or poor construction. The visible signs will tend to be cracking, spalling or mineral deposits on the face of the dam. A number of solutions such as new drainage

systems, seepage control through the use of additional upstream layers or chemical treatments or the addition of buttresses to provide additional strength, can be considered. The solutions depend on the exact nature of the problem and the advance of technology. Therefore, they will not be discussed in further detail here. A good example of best practice being used to resolve internal hazards in concrete dams can be found in *Dams 2000* (Scuero *et al*, 2000) where seven options were considered for a dam deteriorating due to freeze-thaw action in the concrete.

4.6.4 Social hazards

“Society” is a greater hazard to the dam owner than ever before. This is not only true in the case of elements of society that are acting outside the law, such as vandals and terrorists, but also of law-abiding citizens.

It is interesting to note that in the year 2000 version of the ICOLD Bulletin “social hazards” does not include terrorism (MacDonald *et al*, 2000). At the British Dam Society conference held in September 2002, one year after the terrible attack on the World Trade Centre, there was a good deal of debate regarding the fact that dams (even those in remote parts of Scotland) are large hazards that cannot be practically protected from terrorist attacks. Nonetheless, measures such as CCTV and other security precautions are being added to some dams.

At the previous British Dam Society conference, held in Bath in the year 2000, a session was devoted to “Environmental implications: benefits and disbenefits”. The authors recognised that “the Environment” included the social implications of dams. The synopsis of Staniforth’s (2000) paper gives a clear impression of the effect that this may have on the prospect for dam construction in the UK. These issues are also considered with regard to the potential decommissioning of some of the dam stock in future years now that the potential negative effects of dams are receiving increasing media attention (Kirby, 2002).

“Within recent decades an ever growing number of well informed, responsible, politically astute and vocal environmental pressure groups have become established. As a direct consequence, any major infrastructure project attracts intense, and more commonly negative, interest from the very earliest stage of inception. This is particularly evident in the case of dam development projects where the construction impacts are protracted and the final benefits often seem to be largely restricted to future generations. There is an urgent need to reconcile the aspirations of promoters and detractors if both environmental and public interests are to be assured responsibly”.

(Staniforth, 2000)

The future best practice is clear, not only to resolve the conflicts those for and against dam construction, but also to address the threat posed by vandals and terrorists, and that is to ensure “dialogue at a high level between senior representatives of the dam fraternity, key players in the environmental field and Government representatives. The objective would be to identify agreed generic areas of concern surrounding dams.... and the identification of a long term strategy for their resolution” (Staniforth, 2000).

In order for this to be possible, some methodology will be required to help these various stakeholders communicate with one another, in a realm characterised by uncertainty. It is hoped that the approach developed through the research discussed in this thesis, will support this effort.

4.7 Conclusion

It is clear that there are a number of sophisticated risk-based techniques that are being applied to facilitate the management of hydro-electric dam systems. However, these methods are dependent on an understanding and probabilistic assessment of failure mechanisms. The speed of progress in moving towards a probabilistic approach is limited by the fact that all dams are unique because even if the basic design is very similar for two dams, the materials used or quality of foundation will vary from site to site. Additionally, the variability in the loading regime is a great cause of risk and uncertainty. Dam operators constantly have to balance the needs of production with safety demands (e.g. balancing the need for spare capacity in the reservoir to smooth out a storm peak, with the need to not spill water unnecessarily that could otherwise have been used for generating electricity). Thus there is clearly a need for a decision-support methodology that can be used to prioritise investment decision and link these to performance until such time as fully deterministic models become available.

The issue of monitoring is another area that contributes to the uncertainty and hazardous nature of dam systems. While best practice is to collect data regularly, using sophisticated means such as ADAS (Automatic Data Acquisition Systems) there is a limit to the accuracy with which hidden signs (such as piping) can be detected, and companies have a restricted amount of resource for studying the data.

Expert judgement forms a major part of decision-making. In many cases, the information may not even be based on a judgement, in the sense that would be recognised by a court of law, because the evidence behind the judgement is not clear. There are a number of centres

of research, such as the Institute for Reliability and Risk Analysis (based in the School of Engineering and Applied Science, George Washington University, Washington DC) who study in detail the difference between a judgement and an opinion, and the reliability of either in supporting decisions. However, what is commonly agreed (Hartford *et al*, 2000) is that *expert judgements* that are not *tractable* are only *opinion*. Even where the judgement is manageable, the decision points must be traceable in order for it to have any strength as a judgment. Additionally, the bias and politics behind the opinion must be made clear if its robustness (and degree to which it is a judgement rather than pure speculation) is to be assessed. Roger T. Hughes (1996) gives a good example of this bias in his paper “Expert Judgement as an Estimating Method” in which he points out that, during his research, software estimators declared that their top information requirements were “rules of thumb”. These included average productivity rates and the usual distribution of effort between different phases of a project, including conversion factors. Unfortunately, as the respondents noted, the “rule of thumb” was often employed when the thumb in question was that of a more senior manager. Hughes’ paper forms an interesting overview of research into the merits and problems of expert judgement (opinion) for informing decision. The paper concentrates on apparently simple decisions, such as forecasting the time needed for a particular task. The case where the risk is not that of over-running the allotted time but of allowing a dam to fail and cause loss of life is therefore even more important to support reliably.

People working in the dam sector are reluctant to adopt reliability methods. A key reason for this (Blockley 1999a) is that they do not feel that existing models of deterioration and failure mechanisms are sufficiently robust. Equally, it is recognised that there are insufficient data with which to support these models. In some cases, it is not practicable to collect particular data due to disproportionate costs or the possibility of introducing additional risks to human life. The industry is taking steps to ensure that condition characterisation is possible, even under water, through using divers or Remote Observation Vehicles, known as ROV’s (Moxon, 1999). Paradoxically, new technologies of this type present as many questions as they solve. For example, ROV’s cannot access some valves and gates that a diver can reach, but there are obvious safety and economic benefits that result from using an ROV instead of a human. The industry needs a methodology for making such decisions about the type and frequency of monitoring, explicit and auditable.

While proponents of the newer risk-based methodologies identify a number of benefits, some of these can be challenged. In particular, assertions that *all* failure modes and “all hazards can be systematically identified and considered” (Hughes *et al*, 2000b) are overstating the

certainty that can be derived given the inherent uncertainties relating to the type, scale, effect and timing of hazards as well as the exact condition and likely behaviour of the dam itself. While more detailed analytical methods can be used for those parts of the system that are understood, particularly the mechanical and electrical parts (Lewin, 1998) the probabilities of failure and derived reliability indices that must be inputted into some of these methodologies can make the task onerous (where they can be calculated) or meaningless (where they can not). Thus, until such time as such numerical assessments are considered robust and reliable (Hartford *et al*, 2000; Hartford, 2000; Hartford and Stewart, 2002, Sandilands and Noble, 1998, McQuaid, 2002) studies that prioritise areas for improvement, rather than give exact probabilities of failure will continue to dominate.

What is needed is a method that enables rapid scenario testing to be carried out that can be linked to a detailed DSS where required and which makes uncertainty explicit. The methodology must also help to make judgements traceable and facilitate debate between people with differing opinions.

While advances in risk assessment, such as the CIRIA project, enable spending to be prioritised for maintenance, repair and renewal tasks, there is still work to be done on improving the understanding of how technical and engineering issues fit into a company as a whole. This is not the fault of the engineers, nor those with whom they need to communicate, but rather due to the fact that currently there is no coherent methodology for modelling these various aspects in such a way as to make them universally accessible in order to facilitate decision-making.

The key conclusions from this research into best practice in the dam sector has revealed that:

- Dam safety has traditionally followed a “standards-based” approach;
- Existing guidance is complicated, confusing and contradictory;
- There is a general move towards risk-based safety management;
- Risk assessment involves making judgements about risk;
- Judgements are generally subjective, with some data to support them;
- Hazards are complex and unpredictable;
- Failure modes are uncertain and some (e.g. piping) are poorly understood;
- It is impossible to be certain that all hazards and failure modes have been identified when carrying out a risk-assessment;
- Communication with stakeholders is an increasingly important issue; and

- “Models are needed to aid understanding and to support probability assignment (McDonald *et al*, 2000).

The following chapter examines the existing best practice in Asset Management in sectors other than the dam sector to identify whether any of these approaches could be adapted to address some of the current concerns in that sector.

Best Practice in Asset Management

5.1 Introduction

It is clear that hydro-electric systems are highly beneficial to society by providing relatively clean energy from a renewable source. However, the risks that are associated with the sector have the potential to kill many people in a single event, which society finds much less acceptable than multiple incidents with fewer fatalities per event, as is the case on the roads. The dam sector is clearly not alone in facing this issue. In recent years the railway industry has been in the spotlight in the UK following a series of high profile accidents that resulted in fatalities. The nuclear industry, a perennial of national debate, the offshore gas and oil industry (following the tragic Piper Alpha disaster), and the chemical manufacturing industry, are all highly regulated because they are considered to be extremely hazardous.

In this section, the current best practice in Asset Management in infrastructure-based industries will be reviewed and critically assessed. According to the International Infrastructure Management Manual (IIMM), published by the recently formed Institute of Asset Management (IAM, 2002), there are two levels of Asset Management, “Basic” and “Advanced”. Their key features form the topics for discussion in this chapter (Table 5.1).

| Table 5.1: Basic and Advanced Asset Management (IAM, 2002) | | |
|--|-------------|----------|
| Feature | Advanced AM | Basic AM |
| Asset Register | | |
| Maintenance Management Systems | | |
| Job/Source Management | | |
| Inventory Control | | |
| Condition Assessments | | |
| Defined Levels of Service | | |
| Predictions based on basic cost/benefit models | | |
| Predictive Modelling | | |
| Risk Management | | |
| Optimised Lifecycle based Decision-making | | |

5.2 Asset Register

The author has found during the course of this research that solutions given the title “Asset Management System” are commonly asset registers, rather than applications to support the decision-making required during asset management. The IIMM (IAM, 2002) gives guidance on how to evaluate Asset Management Software, which covers a broad spectrum of asset management issues (from registers, through lifecycle planning, to job planning).

5.2.1 Asset Management Systems

A simple asset register might comprise a list of existing assets, and basic “asset management” systems act as asset tracking devices. For example, bar codes may be used on posters, computers or other equipment, which, when scanned, reveal key information about the asset. For this reason, “stock control” modules frequently form a central part of asset management systems. For example, the Hardcat asset management system (www.hardcat.com) links “Stock Control” with “Barcoding” and “Purchasing”. This kind of system is frequently what is thought of as an Asset Management System, but is generally only used for making decisions about “saleable” or moveable assets.

5.2.2 Asset Registers

Asset registers are frequently developed in the form of “Asset Hierarchies”, several examples of which are given in the IIMM. These are closely linked to the traditional view of physical assets as captured in existing risk management techniques. A common split is “asset” (e.g. Water storage), “Facility area” (e.g. Reservoir) and “component” (e.g. main structure, valves). This reflects the schematic shown in Figure 4.4. However, these hierarchical decompositions are difficult to keep in a logical format. For example, is a spillway a component, or an element of a component; and what about the gate on a spillway? Indeed, the focus on assets as having value in their own right is somewhat misleading, because the value of an asset comes from its functionality as much as from any notional “rebuild” value.

Part of the asset register will be an identification system. Despite the advances in computing power that mean a random unique identifier can be used for any given element (with a search function able to track the asset via key features), the IIMM recommends that assets be identified by one of four numbering options:

1. Street sequential numbering (e.g. for water and gas mains);
2. Service and Property Identification (e.g. for sewer laterals and water service pipes);

3. Grid Reference or Plan Numbering (e.g. for “point” assets, such as valves and reservoirs); and
4. Catchment Numbering (e.g. for sewers and stormwater).

A number of norms are suggested, such as numbering from the lowest outlets, following the direction of flow back up a catchment, however, in the opinion of the author, these identification systems are essentially meaningless except for the most basic of paper systems. Instead of entering codes for “area” and “asset type” a drop down list with the real name of the area or asset should be made available for the user. The only critical aspect with regard to asset identification is location. This can be relatively simple for point assets (e.g. individual valves) but can be difficult for networks or large asset bodies, such as reservoirs. One of the ways of overcoming this, and deriving a number of other benefits is through the use of GIS (Geographic Information Systems).

5.2.3 GIS

“A geographic information system (GIS) is a computer-based system for capturing, storing, checking, integrating, manipulating, and displaying data using digitized maps [where]...every record or digital object has an identified location [allowing]...users [to] increase their productivity and the quality of their decisions”.

(Turban and Aronson, 1995)

In essence, a GIS asset register displays assets in relation to their location on a “digitised” (computerised) map. This can be overlaid with photographs or maps (current or historical) to provide further richness. A popular system that can help organisations to link their web and telephone help services to their maintenance and repair work, is the Hansen system (www.hansen.com).

Sometimes the GIS form of demonstrating data can mask key information. Therefore, particularly in the case of networks, the information may be displayed in a linear format, with colour codes to denote key information. This approach has been successfully utilised by water companies where the information displayed might include:

- Age of asset;
- Diameter of pipe;
- Years since last intervention; and
- Frequency of inspections, etc.

5.2.4 Conclusions

The asset register must be the basis for decision-making, because unless an organisation knows what assets it has, it will not be able to decide what to do with them. However, the information stored in a register of this type, and the ease with which it can be accessed, varies from organisation to organisation. The system can only be useful if it contains the data and information required to support decisions. This should include some assessment of the current condition of the asset, and the work that has been, or is to be, undertaken on it. Nonetheless, even registers with a good deal of information contained within them do not really inform decision making to the extent that software specialists might suggest. The reason for this is that they do not link to *processes*, so it is not easy to visualise how an action on a physical assets will have an effect on the overall performance of the system as a whole.

5.3 Maintenance Management Systems

The aim of maintenance management is to determine the optimum period of intervention, which minimises cost while not having an unacceptable impact on risk. Essentially, it is about balancing proactive and reactive maintenance to receive the lowest whole life cost. The IIMM (IAM, 2002) describes areas of planned and unplanned maintenance, as shown in Table 5.2.

5.3.1 Planned and Unplanned Maintenance

| Table 5.2: Planned and Unplanned Maintenance Activities (IAM, 2002) | |
|---|------------------------|
| Planned | Unplanned |
| Preventative maintenance | Corrective maintenance |
| Servicing | Repair |
| Condition monitoring | Redesign |
| Corrective maintenance | Modification |
| Throw away | |

The IIMM recognises that not all maintenance can be preventative, and that some failures will occur “because the rate of deterioration cannot be predicted with complete accuracy and/or because random failures, not associated with the identified failure pattern, occur” (IAM, 2002).

The IIMM acknowledges that the maintenance activity should be linked to the reliability that is required from that asset. This must entail an assessment of the criticality of that element to the performance of a system as a whole, although this link between maintenance planning and risk assessment is not clearly drawn in the manual. The IIMM touches on the issue of linking reliability to maintenance regimes and explains that this requires an understanding of:

- The failure rate (number of items likely to fail over a selected period);
- Likely failure model (historical and potential);
- Failure characteristics (e.g. random, on commission, or deterioration with age); and
- Potential for planned maintenance (whether failure can be predicted).

5.3.2 *Reliability Centred Maintenance (RCM)*

Reliability Centred Maintenance (Martorell *et al*, 1995/1998) was developed in the aircraft industry and attempts to optimise the frequency of maintenance activity to minimise cost while retaining an acceptable level of robustness in the system. Again, while this approach has been applied successfully and is now being extended across a number of sectors (Woodhouse, 2001) it is still dependent upon having some understanding of the failure mechanisms of an asset. While this can be achieved in the fields of manufacturing, or production, it is much more difficult in sectors such as the hydro-electric dam sector, where the key assets (especially dams) are essentially unique and failure mechanisms and frequencies are not fully understood.

5.4 **Job/Source Management**

The area of job and source management is similar in asset-intensive industries to that in other sectors. However, there are a number of constraints within which the organisations must act. For example, those wishing to maintain a rail network must work hard to ensure that possessions (times when the track is closed) are utilised to their full extent and have a minimal impact on the service provided to the customer.

Supply chain management is another area that is gaining a good deal of interest. It has become clear to the author that change tends to be driven by the interactions and boundaries of an organisation, or departments in that organisation. This is because those writing contracts to procure services must ensure that they are written in such a way that ensures that the work carried out delivers the needs of the stakeholders.

The way in which a contract is managed will depend to some extent on the way in which risk is shared. For example, Service Level Agreements will generally leave most of the risk on the shoulders of the principal organisation, while BOOT (Build, Own, Operate and Transfer) and PFI (Private Finance Initiative) shift much of this burden to the contractors. What is needed, however, is some indication of how activities carried out by any member of the supply chain impact on the delivery of the service to the end user.

5.5 Inventory Control

In the view of the author, Inventory Control can be considered as the facet of asset management that looks after those small, moveable, elements that support asset management. For example, control will be required on an inventory of nuts and bolts. While the IIMM mentions inventory control as a key element of basic asset management, in the view of the author, Goldratt (e.g. Goldratt, 1990) has the most advanced understanding of the importance of inventory. The ideas of JIT (Just In Time ordering), which were developed in manufacturing, are transferable to other asset management areas. However, as with the other elements of asset management, success is dependent on being able to predict the future behaviour of the system.

5.6 Condition Assessments

The IIMM provides some guidance regarding the way in which condition assessments can be carried out. The main thrust of the ideas is that some scoring system should be used. This is typically a condition rating of 1 to 5, where 1 is excellent condition and 5 close to failure. Of course, the acceptable condition of an asset will depend on the use to which it is to be put and its criticality as part of a wider system. Therefore, organisations may choose to weight the condition score for a particular asset or asset type to reflect its importance to the performance of the system. This is a somewhat crude approach since, while the condition of a deck may be more important from the point of view of a “business” than the state of the columns, this will depend on the performance viewpoint.

5.6.1 Business-driven weightings

The IIMM suggests that the weighting to be applied to a particular physical element should reflect its business importance, which would take into account factors such as “utilisation, risk to community, level of service, cost to maintain, demand for service and urgency to upgrade the service”. In the view of the author, it is nonsense to suggest that one number can take all these elements into account: indeed, one physical asset may have more than one

use and will certainly have many facets of performance. Hence, while railings on a road bridge may score half that of a deck, their structural condition might be important if one were to consider the devastating consequences that might occur if they were to fail to stop a large vehicle dropping onto the road below. Hence, the context within which the asset is placed will also affect the weighting that should be applied to a particular aspect.

In addition, in the examples given in the IIMM, the systemic effect that poor performance of one element (such as a column or girder) could have on a more “critical” element (e.g. the Deck) is ignored. Hence, weightings can only be usefully applied with a wider understanding of the interactions within the system.

5.6.2 *Soft and Hard Assets*

A case study of the asset management of parks and reserves provides an interesting insight into the way in which “soft” and “hard” assets can be managed. The example proposes that “soft” assets are referred to as “values” (e.g. Recreation; Landscape; Ecology; Heritage; and Culture), while “hard” assets are tangible infrastructure (e.g. Playgrounds; Bridges; Toilets; Buildings; and Other). Interestingly, these are handled through a “dual approach to condition assessment”, where both assets are assessed with regard to Performance (against objectives through audit) and Condition (against minimum standards). The “Values” are also assessed against Trends (e.g. halt degradation) while the “Assets” (hard assets) are assessed according to Priority (e.g. whether the assets are “critical”).

The author believes that such a separation of values (e.g. needs) from the physical asset is artificial and can result in important issues being overlooked. Instead, since the physical assets are in place to deliver a service (“value”), it seems logical that this link should be made explicit. In the following chapters, the efforts made throughout the course of this research to link asset to process will be described. For example, the CMAM research team experimented with a new term of “POPE” (Process Orientated Physical Entity), while the proposed methodology centres around process, with the physical enabler (the asset) expressed as essentially an attribute of that process.

The key point to stress is that condition is only a description of the state that is required to deliver a particular level of performance, and that performance is of a particular process. Hence, condition assessments are meaningless unless it can be shown how current or future condition will impact on the delivery of some service.

5.7 Defined Levels of Service

In addition to considering “soft” (value) assets, the IIMM attempts to link asset performance to service through the use of Levels of Service. Those working within the public sector in the UK will be familiar with these ideas as LSAs (Level of Service Agreements) are becoming quite widespread as a kind of contract between the organisation and the public. The IIMM defines a “Level of Service” as:

“The defined service quality for a particular activity (i.e. roading) or service area (i.e. streetlighting) against which service performance may be measured. Service levels usually relate to quality, quantity, reliability, responsiveness, environmental acceptability and cost.”

(IAM, 2002)

The difficulty with a level of service definition of performance is that it is essentially a “step function”; that is, the level is either met or it is not met. In reality, performance is not so cut and dried as this. There will be some performance indicators where certain values clearly do not represent the required level of service, and others where performance is clearly satisfactory. However, the point at which performance moves from being satisfactory to unsatisfactory (or vice versa) is frequently fuzzy and difficult to define.

For example, an LSA to maintain the average temperature in a building at 19°C seems clear-cut. However, the question is whether a deviation of 0.5 °C from that mean would be unacceptable. At what temperature would the room be too hot or too cold? This example also illustrates an important point, that LSAs can sometimes be satisfied to the letter, but not in the spirit of the agreement. Thus, while the average temperature might be 19°C, there could be swings of several degrees about that mean during the course of the life of the LSA. It seems that a slightly more sophisticated approach to developing performance indicators is required in light of the fact that Deming’s maxim “tell me how you will measure me and I will tell you how I will perform” (Deming, 1986) is proven time and again.

5.8 Predictions based on basic cost/benefit models

Cost/benefit analyses are a key decision-making tool; but they are not simple. In order for them to be workable, the cost and benefit assessments must be meaningful. This can be difficult. For example, the IIMM (IAM, 2002) provides an overview of “Asset Valuation”, which attempts to give a monetary value to a physical asset. This can be calculated and expressed in a number of forms, including:

- Comparable Sales/ Market Value (what the market would pay for the asset in its current or some other use);

- Future Earnings/ Cashflow (what the asset could “earn” from a future revenue stream, minus upkeep costs);
- Reproduction Cost/ Modern Equivalent Asset (Valuation based on cost of replacing with similar assets that are currently available, taking into account use made so far);
- Replacement Cost (a replacement cost, usually based on unit rates); and
- Optimised Replacement Cost (replacement cost, assuming most efficient replacement options).

The problem with these methods of calculating the “cost” of an asset is that they are not very convenient for calculating the “softer” values of an asset. Some of these can be seen in Figure 5.1. However, these asset-based valuations are flawed unless they consider the value of the process that is enacted by that asset. In the view of the author, the key to the value of the asset lies in the process that it yields, which may not result in direct earnings or cashflow, but may contribute greatly to the local, national or world economy.

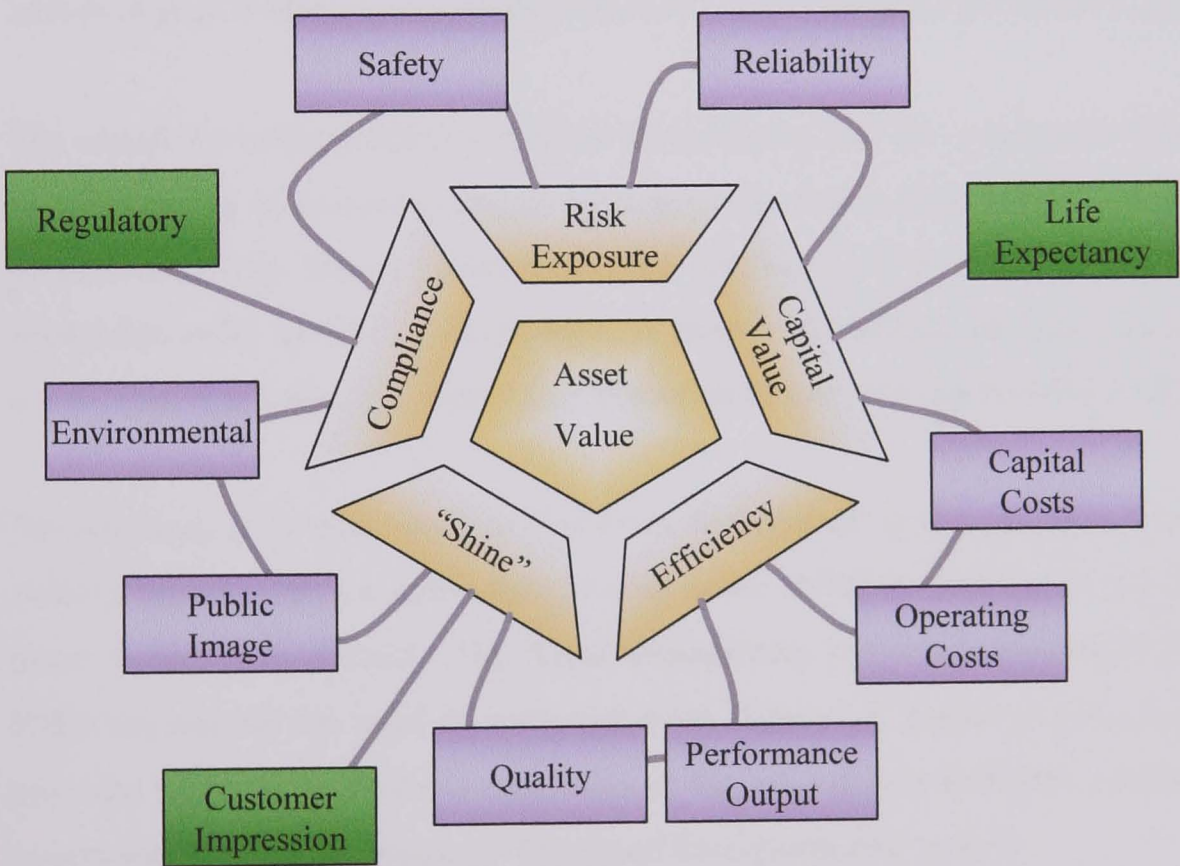


Figure 5.1: “Flower” of Asset Management related characteristics (BSI, 2002)

The issue of calculating the benefit from an asset can also be difficult. Although methodologies such as COBA (Cost Benefit Analysis) have been developed for new schemes, such as bypasses, they tend to be less well developed for existing assets. The European MACRO project (described in Section 5.11) is now considered (by the authors of the IIMM; IAM 2002) to be best practice in terms of carrying out cost/benefit assessments.

Nevertheless, these assessments tend to be heavily dependent on the cost of the benefit of carrying out work (or disbenefit of not carrying out work) with regard to its impact on humans; particularly on human life. For example, the Asset Performance Toolkit (APT) will provide “solutions” that are highly sensitive to the value that is given to human life.

5.9 Predictive Modelling

Predictive modelling tends to be in relation to the future condition and performance of asset. In many cases, the modelling techniques are not reliable. For example, at a recent workshop (September 2003) hosted by the Federation for Water Research, participants were asked to contribute to the ideas of developing “standards” for the water sector. One of the key obstacles at the centre of the debate was the fact that methods for predicting the future condition and behaviour of buried pipes are very crude. On the whole it is only possible to predict the overall condition of a group of assets, and predicting the condition of a particular stretch of pipe is almost impossible (due to the lack of inspection records available).

The search for better predictive models is continuing, but the investment in these tools must be tempered by an understanding of the impact that they will have on decision-making. This in turn is closely linked to the perceived criticality of an asset; and whether failure is acceptable under certain circumstances. A simple cost/benefit analysis (where the benefit is a reduction in uncertainty) should be a precursor to carrying out detailed predictive work.

Nevertheless, it is clear that, as has been highlighted in the previous chapter, decision-making cannot improve much further until some ability to predict the future behaviour of assets is further developed. The Asset Management Publicly Available Specification (BSI, 2002) touches on the need to carry out asset “lifecycle” planning and optimising. While planning has to be carried out regardless of the information available, optimisation will not be possible without the insight to be gained from predictive models.

5.10 Risk Management

It is clear from the discussion above, and from the analysis of best practice in the dam sector that AM is closely associated with risk management. In the UK, the HSE (Health and Safety Executive) takes the lead in safety and risk related issues. The high regard in which their ideas are held can be seen from the way in which high-risk sectors in other countries, including the dam sector in Canada, are drawing on their ideas.

An analysis of recent HSE literature (e.g. HSE, 1989, 2000, 2001, 2002a/b) reveals a number of methods and approaches that are used to manage risk. The main area of interest is the idea of ALARP; that is of risks being reduced to a level that is *As Low As Reasonably Practicable*. This is coupled with the HSE definition of risk; that it is a product of probability (or likelihood) and consequence.

Risk assessment may be fully quantified (event probabilities and event consequences), semi-quantified (e.g. using a risk matrix approach...) or qualitative, depending on the nature and magnitude of the risks, the quality of data and the requirements of applicable legislation or regulation.

(BSI, 2002)

In the view of the author, this understanding of the risk assessment is somewhat naive, given the very real barriers that prevent a reliable quantification of risks, at least where unique, physical assets are concerned. While Risk Management is an established field, which has much to teach the Asset Management school of thought, it may not offer the degree of certainty that is expected of it (as the dam sector has discovered).

The management of risk, now and in the future, is essential to making decisions about how to invest in the monitoring, management, maintenance and renewal of complex infrastructure assets. However, traditional risk assessment methodologies tend to concentrate too heavily on the risk to life and health while other factors, such as “Shine” and the attractiveness of the organisation’s product and image to a client may be equally critical to the continued existence and success of the organisation (BSI, 2002).

These wider “risk” issues tend to be even less open to techniques involving the quantification of risk and are therefore not suitable for analytical study using the tools described above. However, the concepts employed in these methodologies, particular in the FTA, do provide a logical way of thinking of the way in which organisations and their components function as a system. Nevertheless, the author has identified the following key problems with basing asset management decisions on risk assessments. These are that:

- Risk assessments are looking for failure; AM is about looking for success;
 - Successful processes can be harder to identify than failures (which expose themselves from consequences); and
 - Best Practice is less visible and quantifiable than Worst Practice;
- Uncertainty is inherent in quantification of risk:
 - Current methods mask the uncertainty in repeated scenario tests (Monte Carlo simulations etc.);

- Propagation is limited to “yes/no” Boolean approaches;
- Humans tend to provide pessimistic or conservative assessments of risk;
 - because they cannot express their level of confidence;
 - which leads to less than optimal life cycle costs;
- Assumptions and approximations may be hidden by conventional methods;
- Numerical errors (particularly relating to units) can have a large impact on accuracy;
- There may be a tendency to concentrate on numbers;
 - Masking the real issues of improving the “tolerability” of the risk;
 - Escalating the cost and time needed for the analysis;
- Existing models can be prohibitively complicated or overly simplified;
- Attempts to compare risk across industries and between existing and new processes can lead to dangerous assumptions;
- There may be an over-reliance on “expert analysts” and key issues, known by staff at the operational end of the business may be overlooked;
- Dependencies between “input” events can only be considered using unwieldy logic gate functions in the FTA and are ignored in the other approaches; and
- The major risks may be unknown, unknowable, incalculable or unquantifiable.

5.11 Optimised LifeCycle Decision-Making

Optimised Decision Making (ODM) and lifecycle planning are interrelated subjects that are at the heart of the BSI PAS (2002) and the IIMM (IAM, 2002).

“Lifecycle: time interval that commences with the initiation of the concept and terminates with the disposal of the asset”

(BS 3811:1993)

“Optimised Decision Making: An optimisation process for considering and prioritising all options to rectify existing or potential performance failure of assets. The process encompasses NPV analysis and risk assessment”

(IAM, 2002)

The IIMM includes the MACRO (MAintenance Cost and Risk Optimisation) project as a recent “best practice initiative in Asset Management”. The five-year, European, cross-industry project was aimed at collating best practices and develop tools and methods for the risk-based management of physical assets. The Asset Performance Toolkit (APT) was the direct result of the MACRO project, which researched, developed and extended methodologies and tools used to support engineering and maintenance decisions. The APT suite, which is now owned and maintained by the Woodhouse Partnership (www.whpl.co.uk)

comprises six modules, each supporting a different area of the whole-life management of physical assets. The modules are:

- APT-INSPECTION: Optimising cost, performance and other factors that influence operation and inspection strategy to calculate how much to spend on predictive and detective inspection;
- APT-LIFESPAN: Takes account of CAPEX and OPEX costs as well as asset reliability to calculate the resultant life cycle cost as an equivalent annual cost to allow renewal options to be compared based on life expectancy;
- APT-MAINTENANCE: Provides a systematic, structured method for cost/benefit evaluation for temporally varying costs and risk (such as reliability, operational efficiency, falling performance, capital deferment, regulatory compliance, and public image) to determine the optimum maintenance strategy;
- APT-PROJECT: allows the user to carry out a cost/risk evaluation of projects including the situation where demands change over time. Provides a ranked list for competing projects evaluating costs, performance levels, risks and return on investment;
- APT-SCHEDULE: is used to investigate “piggybacking” opportunities in possession management (particularly useful in railways and other linear assets where possession is a key costs). Can also be used to group work such as inspection strategies for geographically diverse assets; and
- APT-SPARES: optimises the stockholding of stock-holding of slow-moving “insurance” spares and consumables through evaluating cost, supplier lead-time, criticality and pooling-options to find the optimum balance of cost of storage with risk and impact of unavailability.

It is clear from viewing Chapter 4, regarding the best practice in the dam sector, that this tool could be of benefit to dam owners and operators. However, while the ability to stock the right level of spares, for example, would be useful, there are a number of uncertainties that almost preclude this. For example, the availability of spare parts for turbines might not depend simply on lead times, but also on the fact that key suppliers may go out of business or “run-down” particular designs, making it impossible to source parts.

With regard to optimising maintenance and inspection regimes, there are some clear difficulties. For example, as has been explained in Chapter 4, it is by no means easy to estimate the “risk” posed by a dam. Even where inundation studies are undertaken, it is impossible to accurately predict the loss of life that might result. In addition, the probability

of failure of the dam and appurtenant structures cannot be predicted with any great degree of accuracy given the current depth of probabilistic knowledge of failure available in the industry (Hartford, 2000; Hartford and Stewart, 2002).

These problems can be overcome to some extent by carrying out sensitivity analysis by changing the input values. However, the amount of work that would be required to enter different values for every possible scenario for each aspect of inspection, life-cycle analysis, maintenance, project management, scheduling and spares management, for each aspect of the physical system, would be a large task. It is therefore recommended that the APT should be a toolkit that is coupled with the methodology described within this thesis so that uncertainty is managed in a more visual, easy to understand manner, and the number of scenarios to be tested through the APT can be minimised through prioritising those processes that have the greatest effect on the overall, service-focused, aims of the organisation.

5.12 Quality Management

Neither the PAS nor the IIMM mention “Quality Management” as a tool for determining preferred asset management options. However, reading of Deming (1986) reveals a number of parallels with that which modern AM is attempting to achieve. Of most relevance is that Quality Management (QM) should pervade an organisation, with everyone contributing to the delivery of a service; and that the focus of activity is the end customer. In comparison to the five-hundred or so words of the IIMM that are given over to “monitoring the overall performance of assets”; Deming and his followers (particularly Wheeler, 2003) have dedicated volumes to considering how customer-facing performance is affected by the type of activity that is undertaken. More discussion of the contribution of QM to this field is given in Chapter 6; further details are not given here, since QM is not currently a recognised facet of AM.

5.13 Value Management

The IIMM (IAM, 2002) explicitly refers to Value Management (VM) in the glossary, but does not give much detail of the techniques involved. Part of this may be due to the fact that VM or VE (Value Engineering) and the Value Method can appear to be a somewhat mystical science. Some of the key concepts within modern AM, such as lifecycle costs and the evaluation of Value (as a ratio of Worth/Cost) are taken directly from the field of VM (Martin, 1997).

The author believes that AM has overlooked some of the key strengths of the VM approach. In particular, the FAST (Functional Analysis System Technique) methodology (Martin, 1997) could be of use in the field of AM. Nevertheless, VM falls down through appearing to be too systematic, organised and procedural. For example, the methodology suggests that a team should include five experts (Design, Operations, Cost, Outreach and Catalyst). While this makes a good deal of sense when comparing various options to resolve a particular problem, it does not provide as much richness and flexibility as might be provided through the use of another approach (such as Checkland's "Soft Systems Methodology"; Checkland, 1981).

An enhanced Asset Management methodology might benefit from drawing together existing best practice with the principles of Quality Management, Value Management and "softer" thinking tools, to provide a more comprehensive understanding of the system, and support improved decision-making.

5.14 Conclusion

The existing best practice in Asset Management, as expressed in the IIMM (IAM, 2002) and the BSI PAS 55 (2002), is fairly comprehensive, but is "loose" in many areas. In particular, the use of Level of Service Agreements (LSAs) is not sufficient to link activity to a clear improvement in performance in the eyes of the customer. In addition, as Deming (1986, 1994) and Quality Management teach us, the Voice of the Customer (what is needed) does not always coincide with the Voice of the Process (what the process can do). In addition, both voice are dynamic and are not always easily understood.

The "customer" placing a demand on a process may not be visible. For example, in one sense, an earthquake might be considered as a variable "Voice of the Customer". Existing AM methodologies do not enable these "demands" to be translated into action, because the AM planning focuses on hierarchies of physical assets, and does not capture the processes that are being undertaken within and between them.

Essentially, the job of the management of an organisation is to translate the demands of various stakeholders into a vision or mission. All lower level processes *should* then be aligned underneath this mission. However, in the author's experience during the case study and subsequent work with the Highways Agency, a water company and several local authorities, most employees within an organisation will not know the mission statement for their own *department*, let alone the organisation as a whole! This is not always their fault.

because the mission statements are often wordy, vague and have no clear relationship to any individual's work. Recent work with local authorities suggests that this is even true in the case of organisations that are implementing performance improvement systems, such as the EFQM Business Excellence Model.

What is needed is a dynamic planning system that enables the organisation to demonstrate how the actions of a group or individual can contribute to the success of the system as a whole. While Value Management does link decisions to "success", this is not traditionally done for "business" focused success. While the IIMM talks of the strategic, tactical and operational levels, in practice, there is little communication between the strategic and operational levels, since the tactical planning may be fuzzy or non-existent. A methodology is required that can bridge this gap.

At the same time as communicating with people within and outside the organisation, the "Voice of the Process" is also changing. In other words, the management must handle an open system; a "Wicked Problem" (Conklin and Weil, 1999) that gives you the feeling that you are trying to sort out "a bowl of tangled spaghetti that seems to get more tangled the more you sort it out" (Blockley and Godfrey, 2000). The problem is that infrastructure assets, while they may be immobile structures, such as dams, never "stand still". Their condition and behaviour is constantly changing. That would be a difficult problem alone, but coupled with the fact that the stakeholders needs, wants and demands are also dynamic, planning becomes very complex.

For example, during the course of three years associated with Scottish and Southern Energy, the author found that a series of legislation resulted in an ever-changing strategy that fed down through the tactical levels of the organisation, right to the detail of operational. On the strategic level there have been drivers away from refurbishing old schemes and towards developing new, smaller, "run-of-the-river" schemes, to benefit from grants for new green energy production. On a tactical level, a decision was made to convert some generation sets to "quick start" systems, to make the most of high energy prices at times of high demand. This results in day-to-day, hour-to-hour and even minute-to-minute changes at the operational level.

As well as the infrastructure itself being complex, unique and hard to predict, the situation is further complicated by the fact that an infrastructure system comprises not only "hard" structures, but also the human and social components. Thus a "socio-technical" system must be managed. During normal operation this can be difficult enough, but in the event of an

emergency, the behaviour of the system can become quite unstable and unpredictable. Even flood studies cannot give good predictions of consequences, because it is never possible to predict exactly the number of PAR (People At Risk) at any time, nor the way that they will react to any warning.

The combined “socio-technical” system is inherently dynamic. The system itself changes with time, developing different properties and behaviours. Thus, there is never a steady state situation. Even carrying out the same processes in the same way (such as maintenance) will eventually lead to a different outcome as the physical system changes from its “just built” state and ages with time. Even without the stress imposed by physical factors, such as the weather, an asset will begin to deteriorate from chemical changes within the material and the self-imposed load.

Added to this already shifting system is the complexity that the demand placed on that system is also non-linear and frequently unpredictable. Obvious demands, such as the need to generate electricity, may be fairly predictable in the medium-term, but is subject to changes in regulation and Government policy in the longer-term. The short-term demands may be constantly shifting within some predictable demand boundaries, but the exact demand at any moment in time cannot be readily foreseen. In addition, other external forces, such as “acts of God” like earthquakes, storms and lightning strikes, can place an additional, dynamic and unpredictable strain on the system. Since September 11th, 2001, further risks, such as terrorism add still more complexity to a system that is already dynamic and difficult to predict. Indeed, every aspect of the system, from its deterioration mechanism, the interaction with people and the physical demands under which it is placed is non-linear and dynamic.

The very fact that the infrastructure systems (socio and technical) are so complicated means that there is a good deal of risk associated with them. This is because certain behaviours are not known and may only reveal themselves in certain circumstances. For example, at present, piping through embankment dams is poorly understood. As knowledge and understanding of the system grows, aided by new tools, technology and research, new aspects of system behaviour and certain combinations of conditions may be considered for the first time. Just as structural engineers now know which combinations of stresses, strains and moments can lead to failure, the “worst” combinations of other factors will become increasingly understood for other systems, even “socio-technical” ones. In order for this to be possible, new models of behaviour and response must be developed.

Given that we are ultimately dealing with dynamic systems that behave in an uncertain, non-linear manner, leading to unpredictable behaviours in response to equally unpredictable demands, there is clearly a need to investigate the interaction between changing state and demands, to be able to forecast behaviour. The problem is that, while this is sometimes possible in the short term, behaviour and performance become increasingly uncertain, the longer the period of which one tries to forecast. An example of this is the way in which meteorological forecasts tend to be accurate for the next few hours and even a day or two, but, due to the complexity inherent in the system and the ever changing demands (such as wind patterns) are much less dependable for foreseeing the longer term.

Essentially, the discipline of engineering is about improving knowledge about the behaviour of physical systems (and their interaction with “soft” systems) in order to provide increasing knowledge that leads to better reliability and performance, while driving down cost and reducing negative impacts on the Environment. In order for this “learning” process to be possible it is essential to begin with good quality models so that decisions can be based on reliable forecasts of system behaviour.

This search for a method for developing a good quality, robust process model, is the driver for the research within this thesis. Like the process model, this approach is itself a *model* and has therefore been subject, and will continue to be subject to, continual review and improvement. However, the goal has been to bring together the great volume of systems-related thinking and systems modelling into some cohesive, simple, defensible approach.

The International Infrastructure Management Manual (IAM, 2002) recommends building a gap analysis around what it calls the “Asset Management (AM) Planning Components” (see Figure 5.2). These are:

- *Processes* that are required to support effective lifecycle AM (e.g. level of service; knowledge of assets; condition assessments; performance monitoring; audit and review, etc);
 - *Information systems* to support AM processes and manipulate data (e.g. Asset registers; financial systems; maintenance management; customer requests; GIS (Geographic Information Systems); etc);
 - *Data and Information* for manipulation by information systems to produce outputs required for decision-making (e.g. asset hierarchies and attributes; historical condition maintenance data; lifecycle costings, etc.);
 - *Asset Management Plans* identifying the optimum lifecycle management tactics and resources; and
-

- *Implementation tactics* including organisational, contractual and people issues (e.g. corporate sponsorship; training programmes; packaging of contracts; specification of quality, etc).

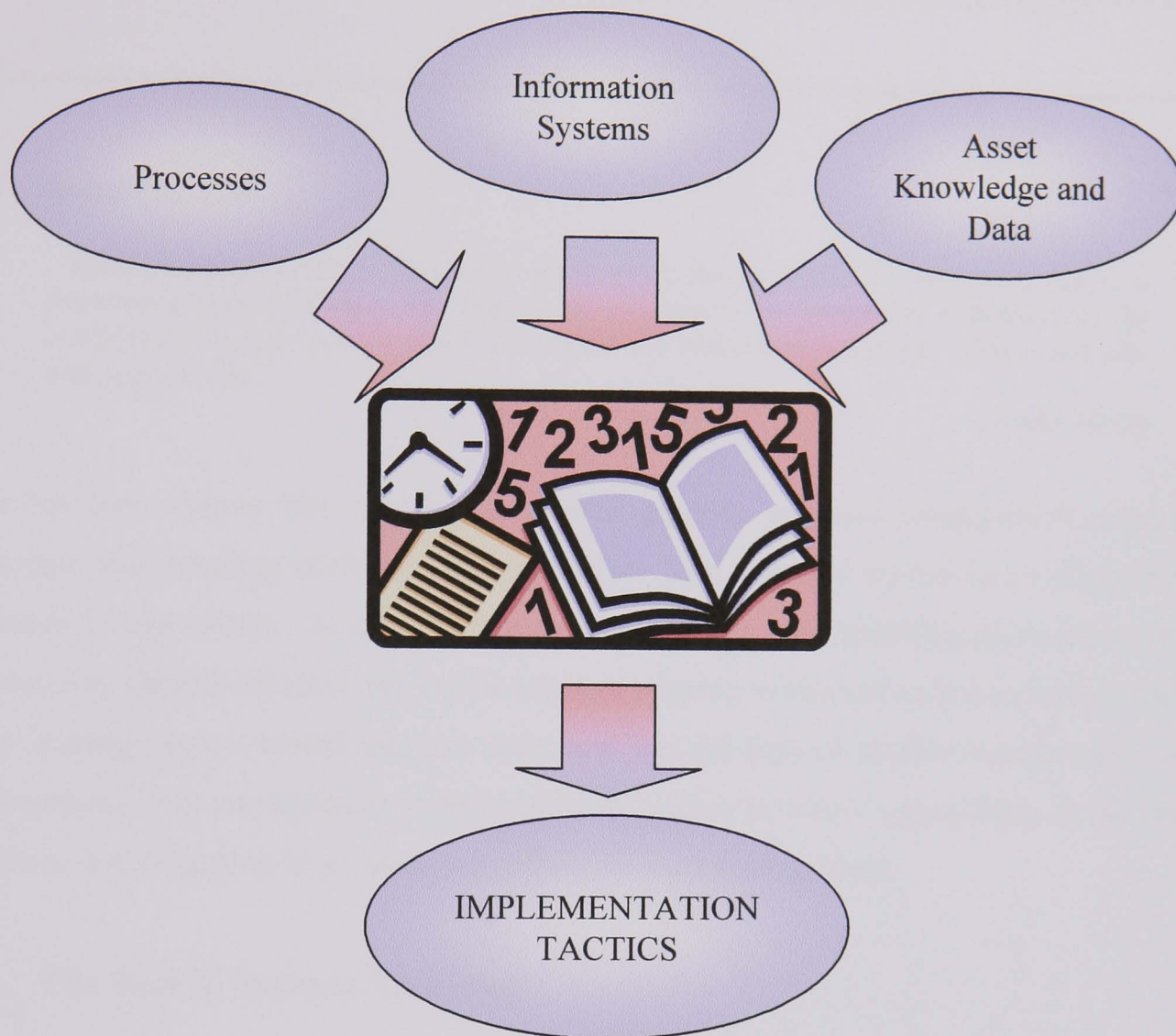


Figure 5.2: Asset Management Planning Components (IAM, 2002)

Clearly there is an ambition to build Asset Management around a framework of “processes” in order to support the existing best practice in AM, and to bring in the best ideas from Quality Management and Value Management. However, the question to consider now is, what methods exist for building models of the systems that are made up of these processes? The next chapter focuses on examining existing systems thinking and process models, to see whether any of these can help to provide more robustness and clarity to the process of AM Planning.

Review of Modelling Approaches

6.1 Introduction

“Systems analysis should be looked upon not as the antithesis of judgement but as a framework which permits the judgement of experts in numerous sub-fields to be combined – to yield results which transcend any individual judgment. This is the aim and opportunity”.

(Hitch, 1955)

The previous chapter has revealed that good practice in asset management requires a thorough understanding of the system in question. It is therefore logical that a model should be made of that system. In this chapter, existing models and modelling approaches will be reviewed to identify whether any can be taken or adapted to support an enhanced approach to asset management; a model that can draw together the best of quality management, value management, risk management to help decision-makers prioritise expenditure in the short-, medium- and long-term to produce true life-cycle asset management.

6.2 The Best in Systems Thinking

By its very nature, systems thinking is a vast subject. While it is possible to force boundaries around areas of study, according to the discipline or era from which the ideas originate, this is a false goal. Capra (1996) describes a “network of knowledge” which is due to the reality that knowledge is “a network of relationships...interconnected....concepts and models in which there are not foundations”.

There are several texts that introduce the history and advances in systems thinking (e.g. Flood, 1999; O’Connor and McDermott, 1997; Senge, 1990; Jackson and McKergow, 2002). The widest and most detailed account can be found in Capra’s beautiful work, “The Web of Life” (1996).

The aim of trawling this vast, complex, interwoven fabric of systems thinking was to attempt to identify “concrete” examples of ways in which these ideas have been used in practice. The author felt that there must be some generic model and/or modelling approach, which could be spliced with the current best practice in asset management to enable decision-makers to have improved confidence and efficiency in their decision-making. What follows

is a brief overview and critique of existing models and approaches, which led the author to the conclusion that further research in the field was certainly justifiable.

6.3 Methodology Requirements

When Bititci and Carrie (1999) carried out their research into an Integrated Performance Measurement System (PMS), they identified a number of key requirements for any model that might be used. The work, which resulted in drawing on Beer’s Viable Systems Model (see below) as the core to its ideas, identified several requirements of each Performance Management System and Reference Model (see Table 6.1).

| Table 6.1: PMS and Reference Model Requirements | |
|---|---|
| PMS Requirements | Reference Model Requirements |
| Reflects Stakeholder Requirements | Describes constituent components |
| Reflects External / Competitive position | Provides guidelines on appropriate measures |
| Reflects competitive criteria | Simple |
| Differentiates between control and improvement measures | Minimises performance measures by promoting criticality |
| Facilitates strategy development | Easily understood and applied |
| Deploys strategic objectives | Independent of organisational structures |
| Objectives deployed to business processes and activities | Dynamic |
| Focuses on critical areas of the business | Auditable |
| Expressed in a locally meaningful terminology | |
| Facilitates resource bargaining | |
| Facilitates performance planning | |
| Focuses on leading measures as well as lagging measures | |
| Accommodates both quantitative and qualitative measures | |
| Measures organisational capability and learning where appropriate | |
| Uses measures at correct levels | |
| Promotes understanding of the relationships between measures | |
| Facilitates simple reporting – demonstrating trends | |

Given the number of collaborators in Bititci and Carrie's (1999) research, which included three leading universities, and given the fact that the focus was, from the beginning, on the development of a PMS (while the Bristol research was looking at wider condition monitoring and asset management issues) it seems reasonable to take the list in Table 6.1 as a yardstick against which the Bristol modelling approach could be compared. Bititci and Carrie (1999) reviewed a number of existing PMS, of which the most famous is the Balanced Scorecard of Kaplan and Norton (Kaplan, 1990; Kaplan and Norton, 1996a/b). The strengths and weaknesses of this methodology have been touched on in Chapter 3 and Bititci and Carrie's analysis concurs with that of the author, in that, while the Balanced Scorecard "addresses" the major stakeholders through the four perspectives ("Financial"; "Customer"; "Internal-Business-Process"; and "Learning and Growth"), the link with stakeholder requirements is not explicit. In practice, working with a number of organisations in various sectors, the author has found that "Balanced" scorecards are often far from balanced, with one major UK government organisation virtually ignoring the needs and demands of staff entirely in a professionally managed "Balanced Scorecard".

Of the "requirements" provided in Table 6.1, the Integrated Performance Management System (IPMS) of Bititci and Carrie, fails to address:

- Balance of leading and lagging measures;
- Accommodating quantitative and qualitative measures;
- Measuring organisational capability and learning where appropriate;
- Facilitating simple reporting of trends;
- Providing guidelines on appropriate measures;
- Being dynamic; and
- Being auditable.

All of these areas (apart from a clear audit trail) are supported to some extent through the Balanced Scorecard. However, the failure of that methodology to express performance indicators in locally meaningful terminology, and to link them to processes, means that the challenge of demonstrating how local action affects overall performance, is overlooked.

The researchers at Strathclyde, Liverpool and Loughborough universities (Bititci and Carrie, 1999) had four stated objectives. One of these was to "research and model the hierarchical structure and relationships between performance measures". In the view of the author, this, and the requirement that the reference model should "describe constituent components" resulted in the researchers focusing on physical elements, rather than processes. The

assumption that there is a natural hierarchical structure and relationship between performance measures *per se* seems flawed. The author believes that such a hierarchy of performance indicators can only be derived in relation to a hierarchical view of processes. Thus, just as the tools of risk management and quality management require a deep understanding of the system in question, performance management has the same need. This is why the final “Integrated Performance Model System” (IPMS) Reference Model of Bititci and Carrie (1999) suffers from the same disaggregated approach as most organisational structures. Even the proposed audit method is centred on understanding the organisation’s structure, understanding stakeholder requirements and then mapping performance measures to meet these requirements. Once again, this “organigram” focus, really misses the point of true systems thinking and reinforces the “silo” mentality that Rummler and Brache (1995) show to be ineffective.

Bititci and Carrie’s (1999) IPMS reference model, like many otherwise excellent “systems models” (including Rummler and Brache, 1995), fails because it divides the PMS into a number of formal layers. Bititci and Carrie stipulate four layers (The Business; Business Units; Business Processes; and Activities), while Rummler and Brache suggest three (Organization; Process; and Job/Performer). This idea of horizontal segregation is as flawed as the hierarchical decomposition that these approaches try to avoid. The issue is that by attempting to draw “boundaries” around layers in the organisation, the system becomes divided into horizontal rather than vertical silos. Indeed, these approaches result in different “models” being applied at different levels of “resolution”. This is why, as Bititci and Carrie (1999) recommend in their model, and as is clearly happening in practice, models such as the European Foundation for Quality Management’s Business Excellence Model (EFQM BEM) are failing. It is precisely because these ideas are implemented by strategic thinkers, that they have no validity or impact in the eyes of those throughout the organisation, despite the extensive “workshopping” and consultation that goes into their preparation. Bititci and Carrie even identify this shortcoming of their own work by arguing (1999) that:

“In collecting data on performance measures used in a company it is difficult to relate a performance measure to a logical part of the business. That is at what level should an existing performance measure belong to: business, business unit or process”.

Bititci and Carrie (1999)

They argue that this is why “the facilitator’s experience becomes valuable during this part of the Audit Process”. In fact, what it more clearly demonstrates is the reason why methodologies such as the Balanced Scorecard, BEM and Six Sigma, become impenetrable and not meaningful for the majority of people within an organisation.

What is needed then, is an approach, which enables an individual or team in any part and at any level within the organisation, to “see” how their personal contribution impacts on the performance of the system as a whole. While attempts have been made to show each individual’s contribution to the organisation, this has historically resulted in a focussing of blame. For example, risk assessments, health and safety training and quality programmes may suggest that “everyone is responsible for..... (risk, health, safety, quality)”, but what is meant is “don’t be the one that messes up our record on.....(risk, health, safety, quality)”. In this new millennium it must surely be time to move beyond preventing failure and instead strive for excellence, not through buzzwords, but through a shared understanding of how individual actions can impact not only for the destruction, but also the betterment of the organisation.

6.4 Beer’s Viable Systems Model

Recognised by Flood (1999) as a “systems guru”, Beer was perhaps one of the first to make a concerted attempt to apply cybernetics to management (Capra, 1996). Drawing on the background of Cybernetics, Beer went beyond the thinking of system dynamics and applies a scientific approach to modelling a system. He argued that two conceptual models are required and that learning comes from comparing one with the other. The models are (Flood, 1999):

- One of the managerial situation of “how the *system* really works”; and
- One from theory of “how the *situation* really works”.

Beer constructs a Viable Systems Model (VSM) by drawing comparisons between the management and organisation of a company and the structure and function of a human brain. It gains the title of “Viable” from the fact that it models a system that can survive (through regulating itself, learning, adapting and evolving (Flood, 1999)). The use of recursion, meaning that the whole can be found in the parts, ensures that the strategy of an organisation is communicated throughout all the levels. The model is quite realistic, incorporating amplifiers, attenuators and transducers to change the required impact of activities. It also includes five “systems” (operations, co-ordination, control, intelligence and policy), which represent different management functions of the organisation.

All this richness is what makes the model attractive to those, such as Bititci and Carrie (1999) who wish to develop or audit Performance Management Systems. However, as even these supporters acknowledge, while the model represents a cybernetic view of the organisations, which is independent of organisational structure (since it exists naturally in all

organisations), any “real” application of the model results in an extremely complicated picture that is neither easily understood nor applied. Thus, a more simplified approach is required.

6.5 Checkland’s Soft Systems Methodology

Like Beer, Checkland is recognised by Flood (1999) as being a “guru” of systems thinking. During fifteen years working at ICI Fibres, Checkland found that existing management science literature was of little help to him and, frustrated, determined to carry out research into systemic thinking (Flood, 1999). Checkland, in the view of the author, brings systemic thinking together with second order cybernetics (an understanding that perception affects the model that is built) to deliver his “soft systems” approach. The word “soft” refers to consideration of people-related issues, rather than solely considering the structure of the system. This is clearly necessary for a truly systemic approach.

In “Systems Thinking, Systems Practice” (1981), Checkland puts forward a seven-stage diagram (Mode 1) to support his soft systems methodology (SSM). Compared to Senge’s systems archetypes (see below), the approach is very fluid in order to support free thinking: the seven stages are not linear but form a learning cycle. The creativity of those exploring the problem is further enhanced through the use of “rich pictures”; cartoon-type figures that allow people to explore their feelings and express their opinions and prior experience. Together modes 1 and 2 provide a methodology for thinking through soft systems, however, they do not provide a clear modelling approach to deliver the kind of systems understanding that is required to support an enhanced asset management methodology.

6.6 Senge’s Systems Archetypes

Thanks to his book, “The Fifth Discipline” (Senge, 1990) is perhaps one of the best known “systems thinkers” of recent times. Senge draws on the background of systemic thinking and cybernetics to deliver simple models for helping people think through the issues within their problem domain. These are known as the systems archetypes and are presented in some detail throughout “The Fifth Discipline” and in the second appendix of that book. They are also outlined in O’Connor and McDermott (1997) and Flood (1999) and “enriched versions” designed to give practical examples, are presented “The Fifth Discipline Fieldbook” (Senge *et al.*, 1994). Kim and Anderson (1998) provide a self-study system for helping the reader to progress from a “story” to an archetype structure. Like Checkland, they recommend beginning by analysing the story with no particular archetype in mind before “trying-on”

each archetype as a “lens” to look at different aspects of the problem. This then is the key, the archetype structures are suitable for looking at aspects of a problem, but become unwieldy if one attempts to use them to build a process model of a larger scale system, at least if any level of detail is required.

Perhaps the most powerful message of Senge’s book is not the systems archetypes but rather the recognition that we cannot know everything. This acceptance of the limits of knowledge, that we may not know everything in due course, is similar to Capra’s (1996) explanation of the networks of knowledge. The important thing is to be able to make decisions in spite of the lack of knowledge. However, there are no “fuzzy” links in Senge’s archetypes; no explicit acknowledgement of uncertainty; something that has been captured in the modelling methodologies developed at the University of Bristol in recent years (see Chapter 7) and which is exploited within the approach suggested in this thesis.

6.7 Goldratt’s Theory of Constraints

Like Senge, Goldratt (1996b, 2000; Lepore and Cohen, 1999) suggests a number of tools for redefining the “problem” domain, through systems thinking, to come up with novel solutions. His overall philosophy, the Theory of Constraints (TOC) revolves around the theory that in any given system there will be one *weakest* link, and by subordinating actions to make the most of that link, the system will be optimised overall.

This view that optimisation of a system cannot occur through a series of localised optimisation attempts, echoes the work of that great thinker, Deming (see below). The synergies between the two philosophers are highlighted in “Deming and Goldratt” (Lepore and Cohen, 1999). However, while both authors highlight the importance of viewing organisations from a systems view (in order that the “whole be greater than the sum of the parts”), neither offers clear guidelines for constructing a model of a complete system.

There are a number of synergies between Goldratt’s TOC and Deming’s System of Profound Knowledge. These are described in Lepore and Cohen (1999) who bring the two methods together to produce a “Decalogue”: a ten-step process designed to achieve continuous improvement in organisations. Unfortunately the second step, “Understanding the System” is confined to two pages and once again only provides a small flow-chart-style diagram (in swimlanes) as the “process model”. While such models may be useful for documenting QA procedures, their usefulness is limited when it comes to gaining a true insight into the

functioning and performance of an organisation, and the use of swimlanes once again flirts with the danger of reinforcing “silo” thinking.

6.8 Deming

W. Edwards Deming is sometimes described as “the father of Total Quality Management (TQM)”. This is ironic as he disliked the term and, even in his polite forward to Mary Walton’s book (1989) gently suggests that he would prefer not to have his work referred to as “The Deming Management Method”. He is perhaps best known for his work in Japan where, in the 1950s, through the teaching of methods for the better management of quality, he is credited for having been one of the key drivers for the change in product quality and dependability that result in that country’s subsequent domination of the market for a number of manufactured goods and products (including cars). For this work he was awarded the “Second Order Medal of the Sacred Treasure” by the Emperor of Japan (Deming, 1994).

Like Goldratt, Deming explains (Scherkenbach, 1991) that without knowledge of the system and how it is behaving, attempts to improve any part of the system will only result in sub-optimisation of the system as a whole (Lepore and Cohen, 1999; Latzko and Saunders, 1995; Scherkenbach, 1991; Deming 1986, 1994; Aguayo, 1990; Walton, 1989). Scherkenbach (1991) explains “even though optimisation can never be achieved, it is always an aim and a limit”. Optimisation can be carried out with respect to two “voices”, the Voice of the Customer and the Voice of the Process (Scherkenbach, 1991; Deming 1986, 1994). These are shown in Figure 6.1.

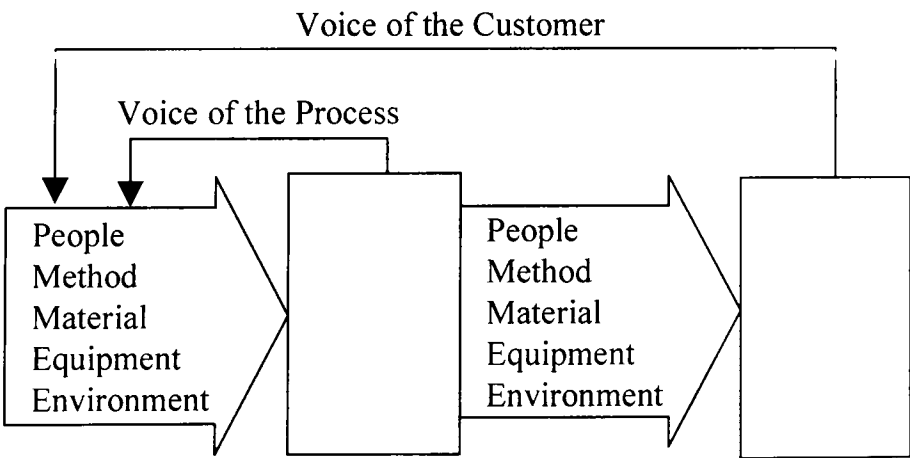


Figure 6.1: Deming’s Voices (from Scherkenbach, 1991)

The Voice of the Customer should be what is driving the organisation and will change over time and “varies from customer to customer” (Scherkenbach, 1991). If it is stable over a period of time, the organisation builds “a degree of belief that the needs and expectations...as you have translated them, will maintain the same pattern in the future”.

The Voice of the Customer is what drives the Goal of Goldratt, the needs of Churchman (Flood, 1999) and defines the boundaries of the system.

The Voice of the Process may be thought of as the data regarding the extent to which the process is meeting the required specification and is also subject to variation. Variation is addressed through the theory of Statistical Process Control (SPC) developed by Shewhart (Deming, 1986). This theory is captured in the principle that “No data have meaning apart from their context” (Wheeler, 1993).

With regard to systems thinking, Deming was ahead of his time in understanding the “soft issues” that impact on the success of a system in ensuring that the process is carried out in such a way that the customer need is met. Deming’s Theory of Psychology predates the soft systems thinking of Checkland (1981), yet it is not recognised by Checkland, or in other comprehensive reviews of “systems thinking” such as Flood (1999), O’Connor and McDermott (1997), or Capra (1996). Deming focuses on two key emotions, Joy and Fear and explains, with practical examples, how management can encourage the former and drive out the latter, increasing efficiency as well as the contentment of the staff.

Deming also leaves us one of the most well known and earliest process diagrams, which he is said to have drawn on a blackboard back in the 1950s when he first went to Japan (Latzko, 1995). This is recreated in Figure 6.2.

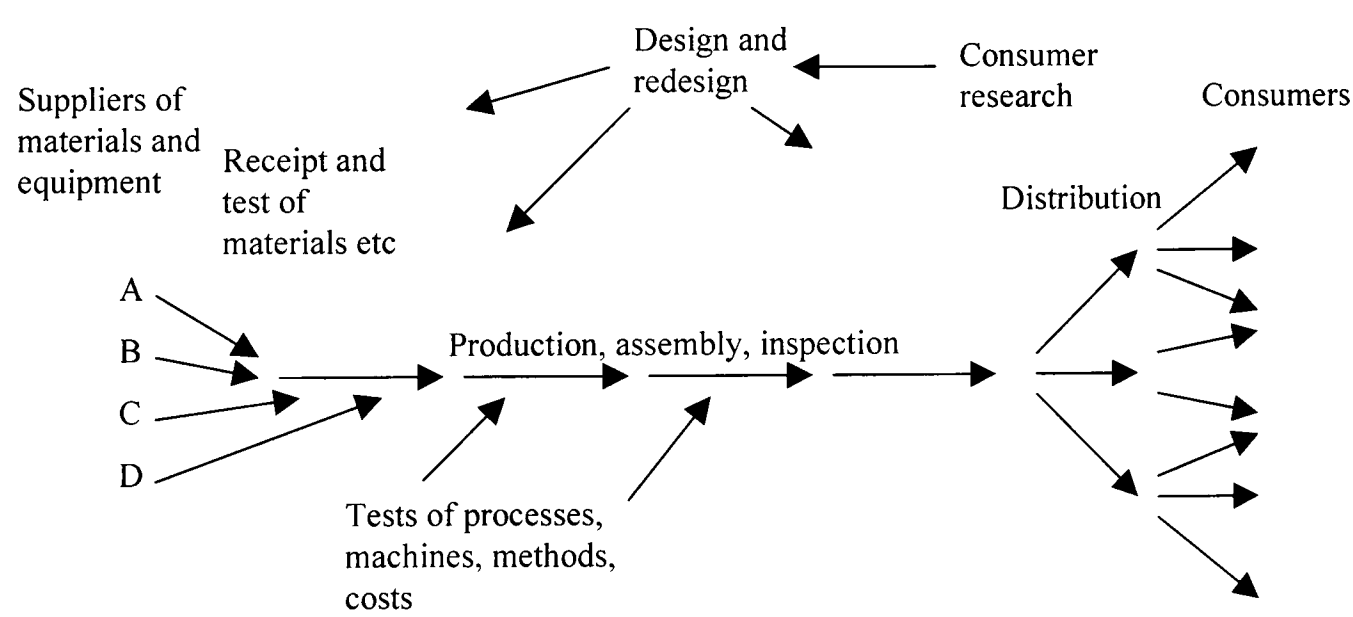


Figure 6.2: Production viewed as a system (Deming, 1986)

Unfortunately, while a flow diagram of this type is clearly an advance on what had gone before, and was a catalyst for quality improvement, it does not provide the link to assets that is required to enhance the current asset management approaches as outlined in Chapter 5.

However, the concepts of input and output; supply and demand, are important to the success of this methodology.

6.9 Quality Tools

The quality revolution that Deming started in Japan in the 1950s, is as vibrant as ever. A number of journals (e.g. Total Quality Management), books (e.g. Dale and Bunney, 1999), standards (BSI; 1991/2000) and Institutions (e.g. the Institute of Quality Management and the European Foundation for Quality Management) have been devoted to furthering the understanding of quality throughout industry. The most comprehensive guide to the various tools and schools of thinking of quality (many of which still originate from Japan) is “The Quality 75”, by John Bicheno (2002). Subtitled “Towards Six Sigma Performance in Service and Manufacturing”, the book describes Eleven Quality “gurus” (including Deming) and various tools and systems support drives towards “Six Sigma” (see below). It also draws parallels between Deming (and Shewhart’s) Plan-Do-Check/Study-Act (PDSA) cycle and the DMAIC (Define-Measure-Analyse-Improve-Control) process proposed by Six Sigma specialists (Pande and Holpp, 2002). The key approaches that might be appropriate for understanding an infrastructure-based system, to enhance asset management, are described in the following sub-sections.

6.9.1 *The Process Map*

Although “process map” is a generic name, it is also the first of the “7 Tools” of Quality recommended by Ishikawa (Bicheno, 2002). This is the process map that has been used during work studies (“time and motion” studies) and comprises specific symbols to represent processes such as “operation”, “delay”, “move”, “store”, “inspect” or “decision”. Like the associated flow chart, these are ideal for checking that work is being carried out in line with procedures, but do not necessarily reflect any impact on performance. In particular, there is no clear link to customer requirements, which are where the required performance levels should be being set. The symbols tend to be specific to manufacturing and are therefore of limited value in the generic asset management. The remainder of the “7 tools”, including the famous Ishikawa Fishbone Diagram (also known as a cause and effect diagram) are of great value in mapping specific processes (as are the risk management tools) but do not support a wider view of performance.

6.9.2 The 6 New Tools

Bicheno (2002) describes six “new” tools of quality that add to Ishiwaka’s original seven. The origins of these techniques are unclear, but they are referred to as the “New” tools in reference to a book published by Mizuno in 1988 (quoted in Bicheno, 2002). Bicheno introduces each tool through a case study looking at a generic problem relating to littering in an urban area.

The first tool, “The Affinity Diagram” is a brainstorming aid for identify how different elements may relate to (have an affinity with) one another. For example, “pedestrians”, “shops” and “fast food” have an affinity with “Town”, while “motorists”, “open trucks” and “public transport” are grouped under “vehicles”. The affinity is extremely loose but might result in the recognition of previously unnoticed themes, requirements, activities or solutions. The relationship between one object and another is not so well defined as the emergent properties captured through the UML (see below) and the lack of formality means that this cannot be considered a modelling technique in its own right (although it might form part of a methodology).

An Interrelationship or Network Diagram can follow on from the Affinity Diagram by attempting to “join-up” different objects and issues. This can be informal or through beginning to consider temporal issues (e.g. a lack of education leads to low awareness and sources of littering, such as lack of facilities and no enforcement, which in turn encourages littering). Once again, the approach is not so formal as the UML, but can lead to an identification of those issues that are key priorities (since they have lots of arrows leading from them to undesirable results).

The next tool is the “Tree Diagram”, which has great similarities with the FAST (Functional Analysis Systems Technique) of Value Management (Kardos, 1993). The approach introduces the idea of “parent” and “child” items. Unlike the Interrelationship Diagram, each child has only one parent, but, in contrast to the FAST diagram, there are no rules for decomposing the model. The idea is simply to “arrange goals, problems, or customer requirements in a hierarchy....it shows how a problem or goal is broken down into more detailed sub-problems or sub-goals” and the most difficult problem, continues Bicheno, “is to ensure that all items on each level are approximately at the same ‘level of resolution’ “. The tool can be improved by adopting the Value Management convention of following the flow of “How” and “Why” through the diagram, and adapting some of Blockley and

Godfrey's (2000) conventions regarding holons (see below). However, it appears that these ideas have not been brought together in any existing methodologies.

The remaining "New Tools" include Decision Trees, which have some parallels in the risk management tools of Event Tree Analysis, Fault Trees Analysis and Failure Modes and Effects Analysis (IEE, 2001a/b/c). The Matrix Analysis tool uses weighting to determine overall scores for various solutions in relation to customer preferences, and has some parallels with Repertory Grid Analysis (Turban and Alonson, 1998) and Multiobjective analysis (Chowdhury *et al*, 2000). However, all of these tools, while perfect for choosing between different, detailed decisions, are currently limited with regard to linking processes to more strategic goals. This research aims to bring together the key spirit and some details of each of these methodologies to enhance the existing approach to asset management.

6.9.3 *The EFQM Excellence Model*

Bicheno (2002) introduces the EFQM's excellence model (formerly known as the Business Excellence Model, or BEM) by explaining that it is a self-evaluation tool for organisations to determine how they are performing and to improve the quality of their service. The European Foundation for Quality Management (EFQM) might be thought of as a European-wide benchmarking of the new international ISO 9001:2000 (E) standard.

The EFQM model (EFQM, 2003) comprises five "enablers" and four "results". The former are "leadership", "people", "policy and strategy", "partnership and resources" and "processes" and the latter are "people results", "customer results", "society results" and "Key performance results". Details of the evaluation criteria for each of these can be found on the EFQM website (www.efqm.org). The author feels that the model is somewhat dishonest in the way in which financial drivers are "hidden" within the model. While Goldratt (1990, 1996) may be seen as extreme in suggesting that the main driver of an organisation is to "make money, now and in the future", the shareholder view is clearly important, regardless of the politically correct use of the word "people" instead of "staff or employees".

Sadly, the EFQM model, while excellent in encouraging companies to improve, is limited in its impact. This is because it is often established through workshops and consultation, but is then "communicated" to staff through a series of posters or some other format that does not "engage" people. What is clearly required is some methodology that results in a model that enables individuals and teams within an organisation to identify the way in which they

contribute to the maintenance of, and improvement of, the overall performance of that organisation.

6.9.4 ISO 9001:2000 (E)

The new international standard on quality assurance, ISO 9001:2000 was published in December 2000 and extends the 1994 standard by enabling organisations not only to demonstrate its ability to meet customer requirements, but also to assess itself. The approach, centred on the Quality Management System pictured in Figure 6.3, is based on eight Quality Management principles (BSI, 2000a/b/c):

- Customer focused organisation;
- Leadership;
- Involvement of people;
- Process approach;
- Systems approach;
- Continual improvement;
- Fact-based approach; and
- Supplier relationships.

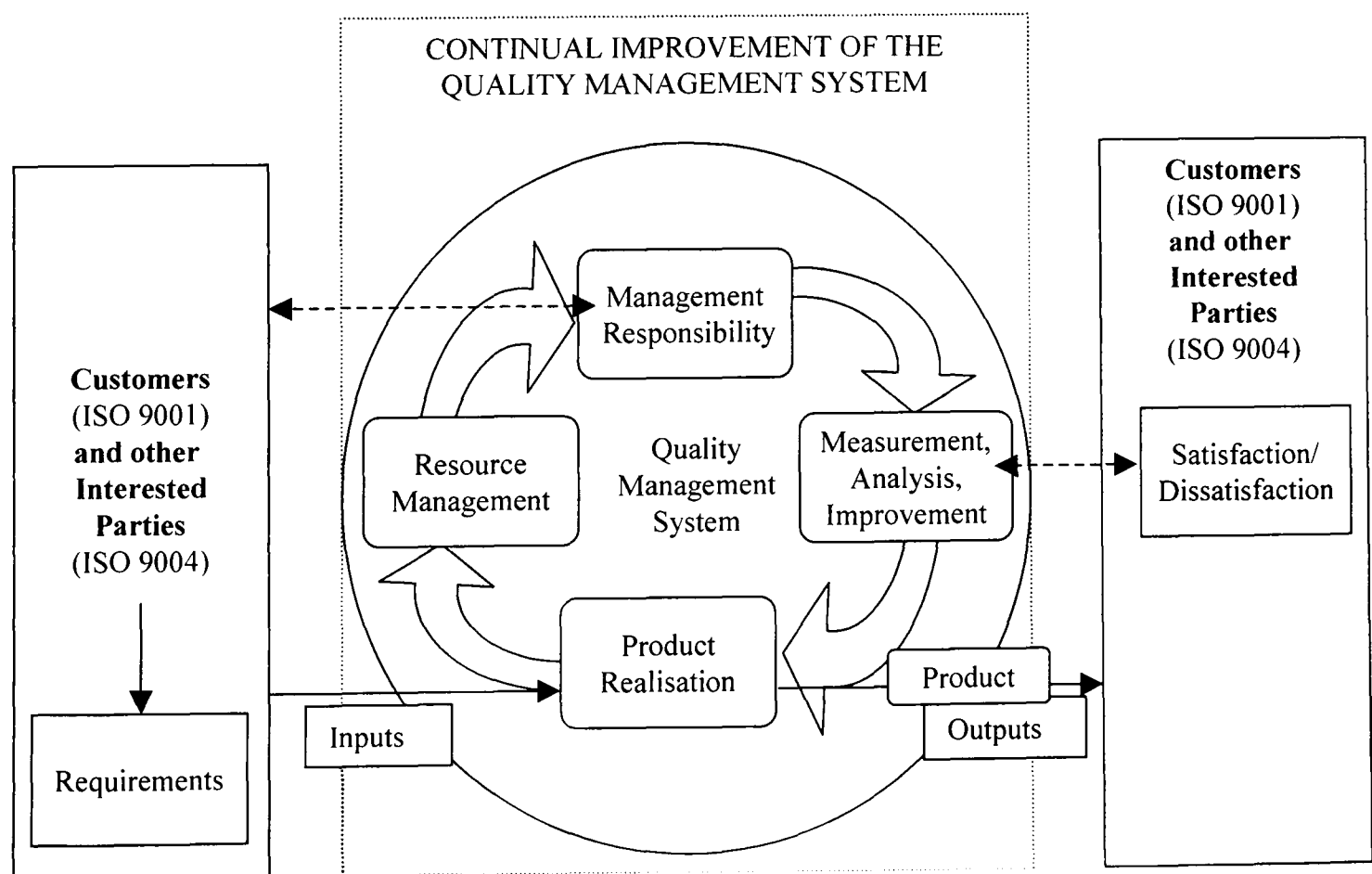


Figure 6.3: The ISO 9001 Quality Management System (BSI, 2000a)

The emphasis on systems and processes is most significant in this context and aims to overcome the “function-based” focus of the previous standard. However, like the work of Rummler and Brache (1995), while the prominence is given to linking horizontal processes, transforming inputs into outputs to meet the requirements of the customer, and overcoming “silo” thinking, the details of how this should be done are not clear. The author attended a workshop (HPO/BSI, 2002) designed to teach people how to build process models in line with the ideas of the new standard and found that the modelling approach was informal, confusing and could not be shown to be robust.

Nevertheless, the process-based focus of the new version of the Quality Standard (BSI 2000a/b/c) is a great advance on the 1994 version. What is needed is some clear guidance on how to build the process models that can be used as the basis of a process model to support the new ISO9001 approach. By providing a holistic view of the processes within the organisation it should be possible to attach performance indicators in such a way as to provide a clear view of performance, which can support the process of continual improvement. By linking processes at the operational level through the tactical level and up to the strategic plans, the goal of truly demonstrating the involvement of individuals can be met.

The aim of ISO 9001 is to enable an organisation to not only demonstrate its ability to meet customer requirements, but also to assess its ability to do this. In this light, some of the work relating to the way in which customer requirements can be modelled, using the enhanced methodology in Chapter 8, should provide benefit for those employing the new quality standard.

6.9.5 Six Sigma

Six Sigma is an approach that has recently been gaining popularity within management circles. It is frequently referred to as “a statistical analysis technique” that originated at Motorola and was popularised by Jack Welch, the former head of General Electric whose Six Sigma work received great publicity in 1995 (Stringer; 2002 O’Connell, 2003). It has recently hit the headlines in the UK with the announcement that the beleaguered Network Rail is planning to apply it to resolve some of its current challenges, particularly in relation to track failure (O’Connell, 2003).

Admirers of Deming and his work (such as the author herself) are disappointed by the lack of credit given to Deming and Shewhart’s work on Statistical Process Control (also known

as Statistical Quality Control). A brief review of the history and detail of Deming's work, from the 1920's at Bell, through the 1950's at AT&T and in Japan, right through to his death in 1993, demonstrates the extent to which Deming's work laid the foundation for these ideas (Walton, 1989). Some authors, cautious of the failure of other "quality" initiatives, such as TQM (Total Quality Management) to succeed in the long-term, attempt to forestay this by describing Six Sigma as an "umbrella" for continual improvement (Pande and Holpp, 20002). The key idea is to embed Six Sigma into the corporate culture by training a number of staff (depending on the size of the organisation and the breadth of the project) in the tools and techniques so that they can continue to apply them in their day-to-day work. The levels of training are referred to as "Belts", in line with the martial arts idea (the colours, from highest level to lowest are "Master Black Belt", "Black Belt", "Green Belt" and "Yellow Belt") and the programme is guided by a Leadership Council with a "Champion" from senior management being selected to oversee the project.

The synergies between Six Sigma and Statistical Process Control (SPC) are great (not least the use of standard deviation to calculate control limits); however there is one key difference. While the charts of SPC (Deming, 1986, 1984; Sherkenbach, 1991) are used to identify which processes are within control and which are out, so that special causes of deviation can be found and eliminated, and common causes can be tackled to reduce the difference between the Voice of the Customer and that of the Process, the "Sigma" in Six Sigma refers to a specification of the amount of variation within the process.

While the process of developing a Six Sigma project, summarised in the acronym DMAIC (Define-Measure-Analyse-Improve-Control) is sympathetic with the Deming/Shewhart PDSA cycle, it still does not inform the process of building a process model.

It is clear then that the quality tools provide a framework for considering performance improvement, but fail to deliver clear guidance to link strategy through to asset management, or the actions and activities of individuals or teams within an organisation.

6.10 Software Modelling Languages

There are two modelling languages that are emerging as approaches for business modelling. The first of these, the UML (Unified Modelling Language) is implemented through the Unified Process (UP) (Larman, 2002). The process is designed to support software development, but the key principles are transferable. The most important of these is the idea

of carrying out development through a series of short, fixed-length mini-projects, called iterations.

There are several accepted disciplines with the Unified Process (UP). These include (Larman, 2002):

- Business Modelling;
- Requirements;
- Design;
- Implementation;
- Test;
- Deployment;
- Configuration and Change Management;
- Project Management; and
- Environment.

The Business Modelling discipline is clearly key to the work being undertaken through this research, but is no less important in software development because it ensures that, particularly in the case of a large-scale application, that the solution will be appropriate for processes across the whole organisation. Therefore, dynamic modelling of the business process is used across the entire enterprise (Larman, 2002). Like the other disciplines, it can be expressed through the twelve main diagrams of the UML. These are divided into three categories:

- Four diagram types represent static application structure;
- Five represent different aspects of dynamic behaviour; and
- Three represent ways you can organize and manage your application modules.

According to the OMG (Object Management Group -www.omg.org), which is the official owner of the UML (OMG, 2003) there are four Structural Diagrams, which are the Class Diagram, Object Diagram, Component Diagram, and Deployment Diagram. Behaviour Diagrams include the Use Case Diagram (useful during requirements gathering); Sequence Diagram, Activity Diagram, Collaboration Diagram, and Statechart Diagram. There are also three Model Management Diagrams: Packages, Subsystems, and Models.

The reason that there are so many diagrams, and why the UML is therefore so helpful in the context of systems-thinking, is that it enables the user to view different aspects of the system. This is important because:

“typically, a system has a number of different stakeholders – people who have interests in different aspects of the system.....Conscientious system design involves all possible viewpoints, and each UML diagram gives you a way of incorporating a particular view”

(Schmuller, 1999).

In addition to the twelve basic diagram types described above and in Appendix C, the UML has also been frequently extended (both within and outwith the bounds of the OMG's specification). For example Hans-Erik and Eriksson (2000) provide a book containing 26 business patterns based on the UML. Although this sounds like a large number, each model follows on logically from earlier chapters. Nonetheless, although the aim of the book is to extend the usefulness of UML to a range of business processes not directly concerned with programmatic information systems, it is hard to visualise any manager sitting down and using the UML to model the process in which he or she is involved. Having said that, the models might be useful for helping a group of people resolving potentially conflicting views, with the guidance of an experienced UML facilitator. For most purposes, however, the UML models can be confusing and overly complex.

The elements that have clear application to the process modelling required during this thesis, and which provide the basis upon which the new methodology is based, are:

- The extended Business Process Modelling function;
- Class diagrams;
- Use case diagrams;
- Sequence and Collaboration diagrams; and
- Activity diagrams (including swimlanes).

The class diagrams are useful because they provide an indication of the physical structure of the system, and the way in which the different elements interact. In addition, the concept of classes and objects with inherited characteristics is useful when considering what should be included as attributes of the generic holon.

The use case diagrams provide an insight into the dynamic behaviour of the system. They help to ensure that everyone has an agreed understanding of the domain. In particular, they can be used to demonstrate how different stakeholders (actors) interact with the system. Larman (2002) identifies three styles for writing use cases. These are:

- Brief: terse one-paragraph summary, usually of the main success scenario;
- Casual: informal paragraph format. Multiple paragraphs that cover various scenarios; and

- Fully dressed: the most elaborate. All steps and variations are written in detail, and there are supporting sections, such as preconditions and success guarantees.

This last version has been chosen, following the rules of headings, success scenarios and extensions described by Cockburn (2001). Its use in capturing stakeholder views is shown in Chapter 8.

Sequence diagrams, which are similar to collaboration diagrams (see discussion in Appendix C) are used to extend the detail captured in the Use Case diagrams. They demonstrate the sequence in which the actor (customer) interacts with the system, and the messages that consequently pass throughout the system. In the case study, the term “message” has been interpreted to mean “energy” in the broadest sense. “Energy” can encompass electricity, the flow of water, or an instruction from one system element to another. The sequence diagram captures the way in which responsibility and action is passed from one department to another in the current system. There is some danger that this view can reinforce the “silo” thinking that is so discouraged by systems thinking (Rummler and Brache, 1996; Capra, 1996), but it has proved to be a convenient way of communicating with experts in the system, who find this a comfortable way of capturing information.

Activity diagrams are similar to sequence diagrams, but somewhat more intuitive because they are in the form of a flow chart. They can therefore support simple decision junctions. The activity diagram can be shown in “swimlanes” (see Appendix C) to demonstrate how each department is responsible for a particular process. Again, there are some dangers in attempting to do this as some processes may be the responsibility of more than one department, and a “swimlane” approach can reinforce “silo” thinking.

The UML is not only useful for the work described in this thesis. During this research, the author has realised that there are potential future applications. These include using it as the foundation of an Expert System (Schmuller, 1999; Turban and Aronson (1998). The ideas can easily be adapted to connect the knowledge of experts and combine a knowledge base (collected through the use of UML interview techniques) with rules, an inference engine, a work area and user interface to build a workable Expert System. A further potential benefit (identified by the author) is that the processes captured through this work could be used as a foundation for Knowledge Management projects (Plumley, 2003).

The IDEF family can provide similar models that can help to provide richness to the model. However, both the UML and IDEF models can appear very complex. Like the process maps

of quality management, there are several shapes that can be used in the model. Therefore, while the diagrams encourage innovative thinking and a “richer” picture (including the needs of the majority of stakeholders), they should not dominate the modelling process. It seems that the “How, Why, When” approach of the FAST diagrams (Kardos, 1993) of Value Management may be a more appropriate route.

6.11 Blockley and Godfrey

Blockley and Godfrey (2000) propose that the mnemonic, BCIOD+R (Business, Customer, Integration, Operation, Delivery and Regulation) should provide the first level of the process model (with the top holon action as Level Zero). This is demonstrated through an example from their book in Figure 6.4.

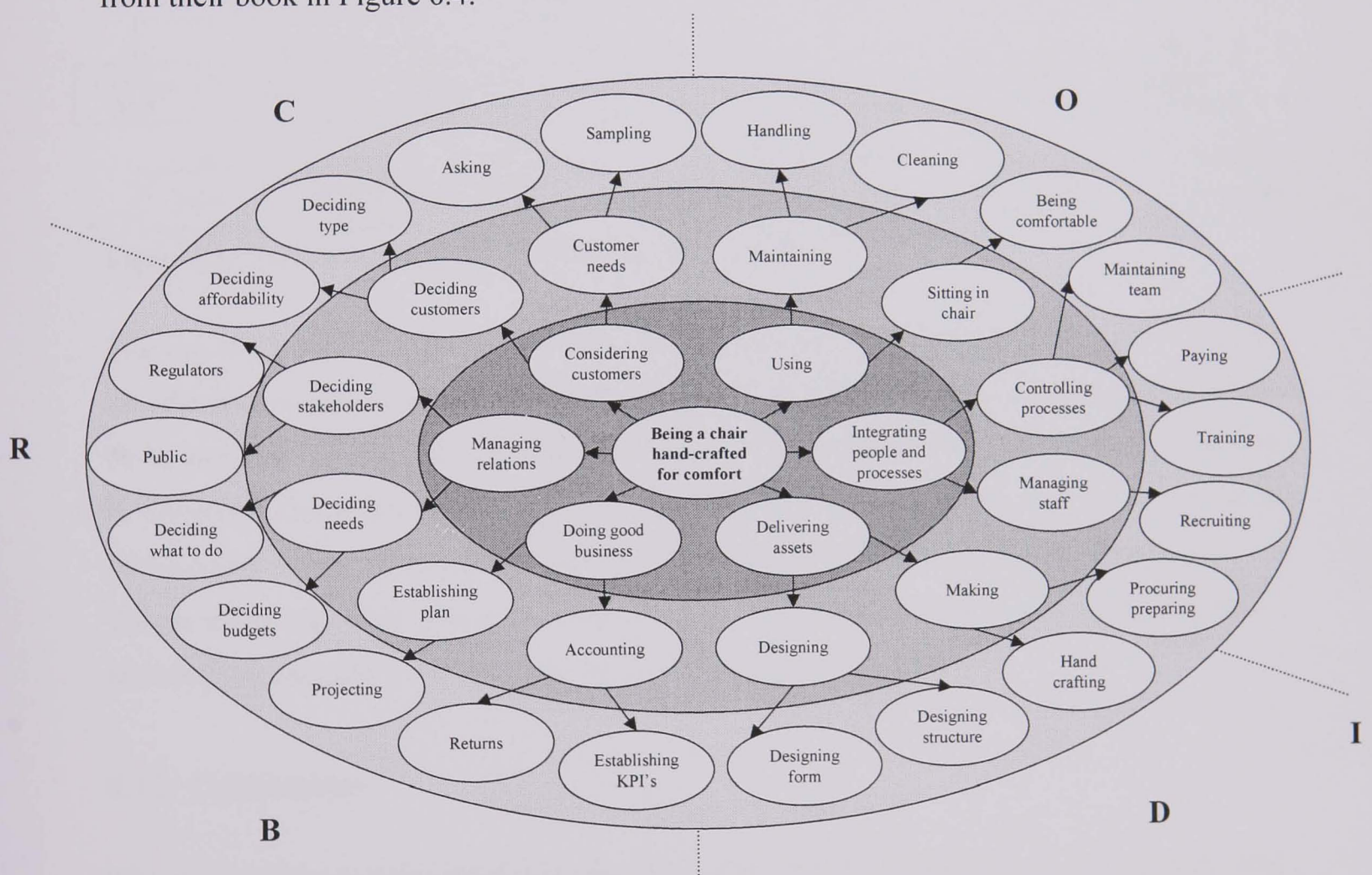


Figure 6.4: Example of employing BCIOD+R (from Blockley and Godfrey, 2000)

Unlike the other models (except the value management FAST diagram), this approach does try to provide some more formal guidance for constructing a model. However, there are a number of points on which this method could be improved. For example, the use of processes such as “being a chair hand crafted for comfort” is not ideal because it does not explicitly link to the user. This is handled better in the UML and IDEF, but these diagrams are quite complex.

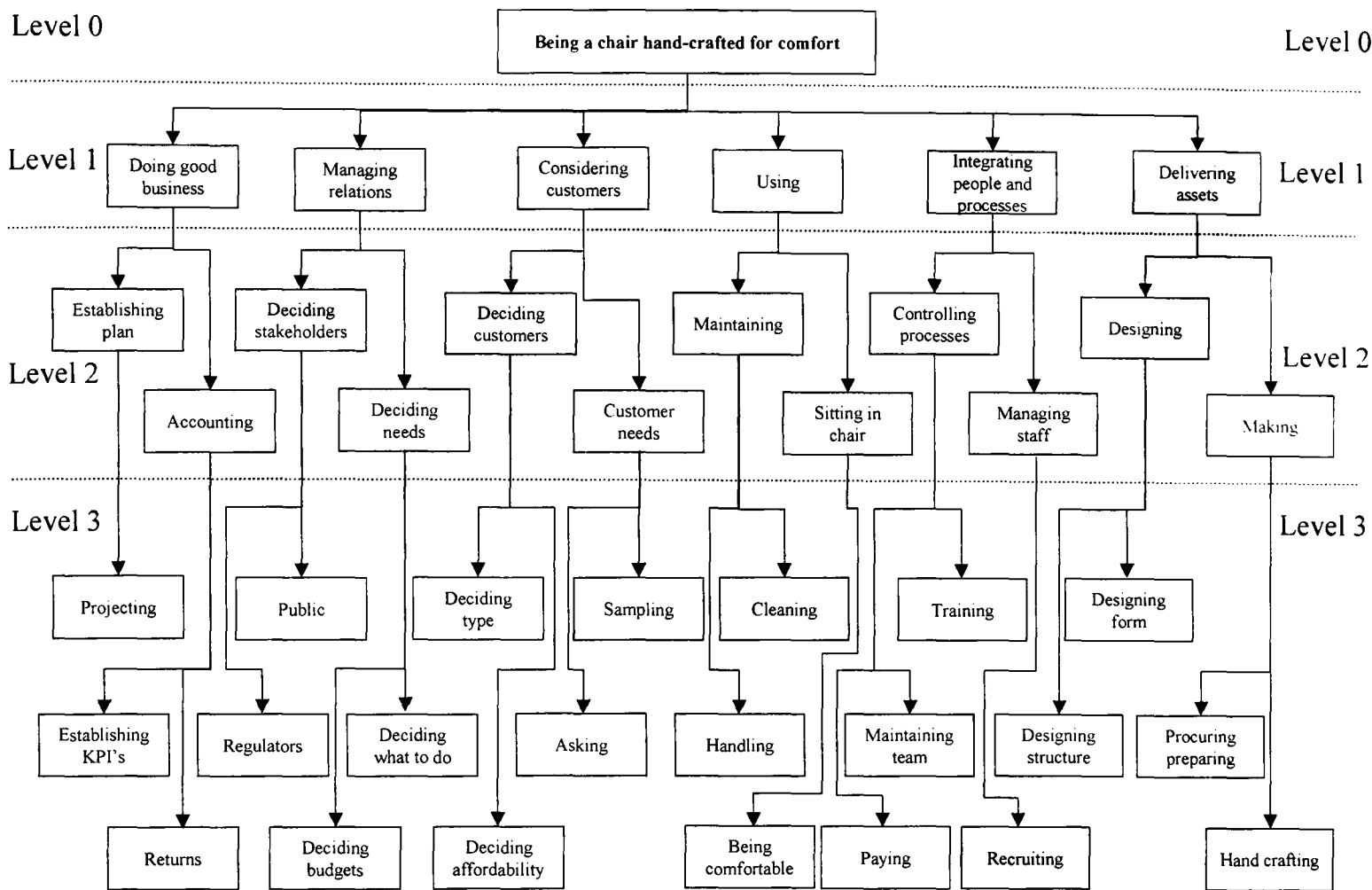


Figure 6.5: Translating the BCIOD+R Circle into a Hierarchy

The use of a top holon such as “Being a chair handcrafted for comfort” is a potential flaw in an otherwise useful methodology. The chair has been designed to be comfortable and is to be handcrafted because these are attributes that are driven by customer demand. As is shown in Chapter 8, the author has chosen to use the top holon to demonstrate the vision or mission of the organisation, which is essentially the management’s synthesis of stakeholder needs. This is more logical as processes such as “doing good business” and “managing relations” are not processes driven by the chair, but by the company that sells it.

6.12 Conclusions

The review of the systems modelling approaches has been summarised in this chapter. There are a number of synergies between the various approaches. In particular, the soft issues and importance of building a shared vision are shared by Checkland; Beer; Senge; and Blockley and Godfrey.

The link between individual or team actions and the effect on the performance of the system as a whole is not clear in the quality management literature nor the performance management system approaches. This can be established the Viable Systems Model, the UML or the IDEF, but each of these approaches result in a model that is too complex for most practical purposes. Since the latest paradigm of Knowledge Management is to drive team learning

through understanding processes (Plumley, 2003) a model is required that is sophisticated enough to capture the detail of a real system, yet visually simple. Therefore, it is essential that the apparent complexities of the quality Process Mapping tool, the UML and IDEF are hidden, while the richness that they provide is not lost.

There are many models of businesses and organisations that have not been covered in any detail in this review; such as the St Gallen business model (Spickers, 2003) and Beer's Viable Systems Model (Flood, 1999). A short search on the Internet will throw up even more examples and a plethora of business process modelling tools (see Appendix A).

What is needed is not another model, but a methodology that can bring together the best elements of those that exist. In short, what is proposed is an approach that will enhance current asset management through understanding that managing assets is synonymous with managing processes. This is because assets only exist in order to enact the processes that deliver the service required by the end user, while balancing the sometimes conflicting demands of a number of stakeholders.

The proposed methodology will make use of the latest systems thinking coming from the Systems Group at the University of Bristol (Chapter 7) and combine this with elements coming from the fields of Risk Management and Quality Management, as well as software development, to provide a framework for decision-making.

The Fault Tree and Event Tree analysis (IEE, 2001a/b/c) of Risk Management meet one half of the need for Asset Management; the need to avoid failure. Quality Management ideas should help deliver the "other side of the coin", demonstrating how interventions can lead to improvements; a kind of "positive risk", where work can be prioritised not only to minimise risk, but also to maximise benefit. None of this is possible in a vacuum, but by bringing together a number of process modelling ideas and linking these to the concepts embedded within value management, plus some novel suggestions for a new vocabulary and practical methods for managing the soft issues involved in modelling, it is hoped that this will result in a step forward in asset management.

The Bristol CMAM Research Project

7.1 Introduction

The research described in this thesis forms part of the work carried out at the University of Bristol during the Condition Monitoring and Asset Management (CMAM) project from the summer of 1999, until the autumn of 2002. This research had the stated aim of developing “new decision support techniques to improve the safety and economic performance of complex civil engineering infrastructure systems” (Hall *et al*, 2001).

The author played a part in the development of some of the ideas that have gone into the new tool (originally called CMAM, and now Perimeta), although much of the work drew on existing thinking at the University, particularly the work that had gone into the Juniper tool. The author did not develop the tool, but did contribute to the discussion relating to the ways in which evidence might be propagated. Her key contribution, however, has been in the development of a methodology which can be supported by the tool, and which is described and developed in Chapters 8 and 9.

The complex civil engineering infrastructures systems considered during the course of the project were those where the decisions made were commercially important or safety critical. Hence, dams, flood and coastal defences and engineered and natural slopes were all considered, since they have many characteristics in common. These were described in Chapter 1 and are that (Hall *et al*, 2001):

- (i) The physical failure mechanisms are complex and site-specific;
- (ii) The structural behaviour is spatially varied: this often associated with natural variability in loading regime (wind, wave, rainfall, seismic) and geotechnical conditions;
- (iii) Monitoring information tends to be scarce and can be expensive (or impossible) to obtain;
- (iv) Expert judgement is usually a major element of condition monitoring (due to the scarcity of quantitative information and the complexity of the physical processes); and

- (v) Condition assessments are characterised by uncertainty, which can result in monitoring and remediation resources being misdirected.

The author focussed her research on the application of these ideas in the field of hydro-electric dam schemes, which display all of the characteristics in the list above. As has been identified in Chapter 4, the key demand coming from the dam sector at present is for a methodology which can support decision-making in the face of uncertainty. In fact, all five of the CMAM characteristics, listed above, are a cause of uncertainty in that sector:

- (i) *Uncertainty* due to unknown and poorly understood failure mechanisms, models of which are themselves not fully tested or trusted;
- (ii) *Uncertain* loading conditions that are not fully predictable in terms of timing, magnitude, or consequence;
- (iii) *Uncertainty* resulting from gaps in monitoring information, and difficulty determining the most cost-effective monitoring regime for reducing uncertainty;
- (iv) *Uncertainty* in the dependency of expert judgement, with some judgements having so little quantitative reasoning supporting them that they are in fact little more than opinion; and
- (v) *Uncertainty* regarding what decision to make, given all the other types of uncertainty inherent in the problem.

One of the main factors that hinders the ability of the decision-maker to make decisions, regardless of the fact that so much uncertainty exists, is that there is no framework available that allows the assumptions supporting the expert judgement to be recorded in such a way that the expert is able to assert that it is indeed more than an opinion. Not only this, but data are not collected and handled in a clean and uniform way. In reality, the decision-maker must be able to bring together “apples and pears” to support the decision. This reveals a need to be able to describe quantitative and qualitative information in the same framework.

While the team of researchers collaborated to determine new techniques supporting decision-making, it soon became clear that one step in the process, that of developing a robust and coherent method for building process models, required further research than has so far been dedicated to the task. This will be discussed in more detail in further chapters. This chapter aims to:

- Describe the background to the CMAM project;
 - Explain the key principles of the CMAM methodology; and
 - Introduce the CMAM/ Perimeta tool developed through that project
-

7.2 A Performance-based View

The CMAM project has resulted in the development of a tool, which allows the user to model any part of a system (perhaps even the whole organisation) and view the way in which it is currently performing. This is done by linking performance indicators, through value functions, to individual processes to give an indication of how they are performing. These indicators then “propagate” up through the system to give an overview of how the system is performing in relation to some goal or idealised level of performance. Switching to a performance-based view of the world (rather than the historic standards-based, or emerging risk-based view) has several advantages. Firstly, particularly in service-focused industries, the shareholder needs can best be met by translating the external performance (service) demand into a clear mission, vision or strategy that can then be disseminated throughout all levels of an organisation. In addition, by focusing on sustainable performance, risk issues will not be forgotten because the failure of a key asset will not be acceptable. In fact, performance-based decision-making and risk assessment are two-sides of the same coin, particularly if one considers that risk can be defined as “failure to meet required level of performance”. Thus, while the CMAM methodology and tool have been developed in the context of systems thinking and of assessing the performance of processes within a system (as shall be demonstrated later in this section) the ideas can be adapted for use within a more risk-analysis orientated culture.

As has been noted in Chapter 4, the management of systems as complex as hydro-electric dam schemes involves a complicated and multi-connected set of technical, economic and environmental issues (Hsieh and Liu 1997, Chowdhury *et al.* 2000, Hastak and Abu-Mallouh 2001). The needs of the company to generate electricity (and money) are clearly balanced by the consideration of the safety of people living near the dams and reservoirs, as well as the needs of the local Environment (particularly fish). In order for robust decision-making to be possible, individuals engage in cycles of decision-making in their own domain, which then contribute to key points of resource commitment in the collective process (Mintzberg *et al.* 1976, Boland *et al.* 1990). In practice, this is done through a process of negotiation, since there are only a limited number of resources. Best practice companies, such as SSE, carry this out by consulting with people on site at regular intervals, with area managers holding meetings with those in charge of reservoirs in a particular geographical location. The area managers then work together to determine spending, in accordance with the budget allocated to maintenance, repair and investment (which is itself negotiated at another level within the organisation).

In the view of the author, this method of negotiation, making best use of the budget available for each department, will not result in the optimum Asset Management solution. Such a system leaves an organisation open to the possibility that departmental budgets will be set on a historical basis (with occasional cash injections for particularly high profile projects) rather than with a view to delivering the desired levels of service. Indeed, this idea of prioritising expenditure locally, based on the negotiated budget, flies in the face of modern management thinking as espoused by Deming and Goldratt (Deming, 1994; Goldratt, 1990). Because the CMAM methodology illustrates how local performance of a particular process affects the performance of the system as a whole, it holds a great promise of facilitating true optimisation.

In addition, because negotiation will still be required, and may, for practical reasons, take place in parallel at several levels within the organisation there will still be the risk that some issues might fall between the “silos” if no one is made responsible for insuring that they are addressed. By using systems thinking this danger can be reduced. For one thing, taking a process rather than organisational view should ensure that all issues are considered and making one person the ‘owner’ for a particular process (Blockley and Godfrey, 2000) should ensure that none are overlooked. Finally, the Perimeta tool, developed in the CMAM project should assist in the journey towards Advanced Asset Management (IAM, 2002) by providing the facility to record the way in which decisions were made, so that continual learning is possible.

7.3 Different Types of Evidence

As has been demonstrated in previous chapters, another key demand in the dam sector and other industries is the need to bring together disparate types of information in order to analyse and evaluate the options available. This is partly a question of rational data management (bringing together various databases into one place), but is also a result of the fact that evidence is found in many different formats. Evidence varies from monitoring data (which can be directly or remotely measured), the output of dense numerical models, information recorded in textual formats (in technical and inspection reports, recorded analogous cases), expert judgements (whether written or verbal) and other “soft” sources, such as the perceptions and value judgements of the wider stakeholder group, including shareholders, environmental campaigners, staff, neighbours, and the natural environment.

Since the evidence upon which decisions are based appears in very different formats, it can be difficult to bring it together in order to support decisions. Decision-makers are left

feeling that they must weigh up ‘apples’ and ‘pears’ in order to make decisions about the way in which the assets should be run, monitored, and invested in. Sometimes the evidence relating to a particular decision may be expressed at different levels of granularity, and may be only partly relevant to the decision, incomplete, or may even conflict with other sources of evidence, which, on the surface, appear to be equally valid.

Despite all these barriers to effective and defensible decision-making, those within the industry recognise the need to address these problems of uncertain data value and meaning, in order to ensure that decisions are robust, and that resources are allocated appropriately. At the same time as pressure is being put on decision-makers to use resources efficiently, the very resource upon which they have relied in the past for decision support, the experts, are disappearing from the field. This is partly due to natural wastage, the down-sizing and right-sizing of the past few decades, and the reliance on out-sourcing of technical services to smaller, expert, organisations (which occasionally go out of business). This means that decision-makers have a clear need to record corporate memory in order to inform the decisions of the future (Marchand *et al*, 2000). At the same time, decision-makers are forced to handle vast volumes of data since, not only is there limited resource to assist them in this task, but also improved communication throughout the industry, coupled with new modelling techniques, are resulting in more and more data requiring processing and consideration (Hall and Davis, 2001).

As has been noted above, the response to these pressures in recent times has been to undertake risk analysis. Experts attempt to prioritise spending needs by calculating the probability and consequences of failure (Robery, 1997). Unfortunately, even where such probabilities are calculable, this does make organisations open to the “Flaw of Averages”. That is, the average time period between interventions will not result in the average MTBF (Mean Time Between Failures) because not all elements are operating in the same state (load etc.). Additionally, the acceptable MTBF for some assets of a particular asset group may be much longer than for other assets of the same type (where the desirable MTBF may in fact be infinite, with failure being considered unacceptable). For example, an aqueduct feeding water into a reservoir at the top of a cascade of dams may be of much more strategic (and safety) importance than one in a remote valley, that feeds water from a limited catchment into a small hydro-electric scheme.

The Flaw of Averages explains why uncertainty and deviation about the mean cannot be dismissed without possible dramatic, and potentially tragic consequences. Consider the

cartoon in Figure 7.1, of the statistician who agreed to wade across a river with an average depth of 3ft.

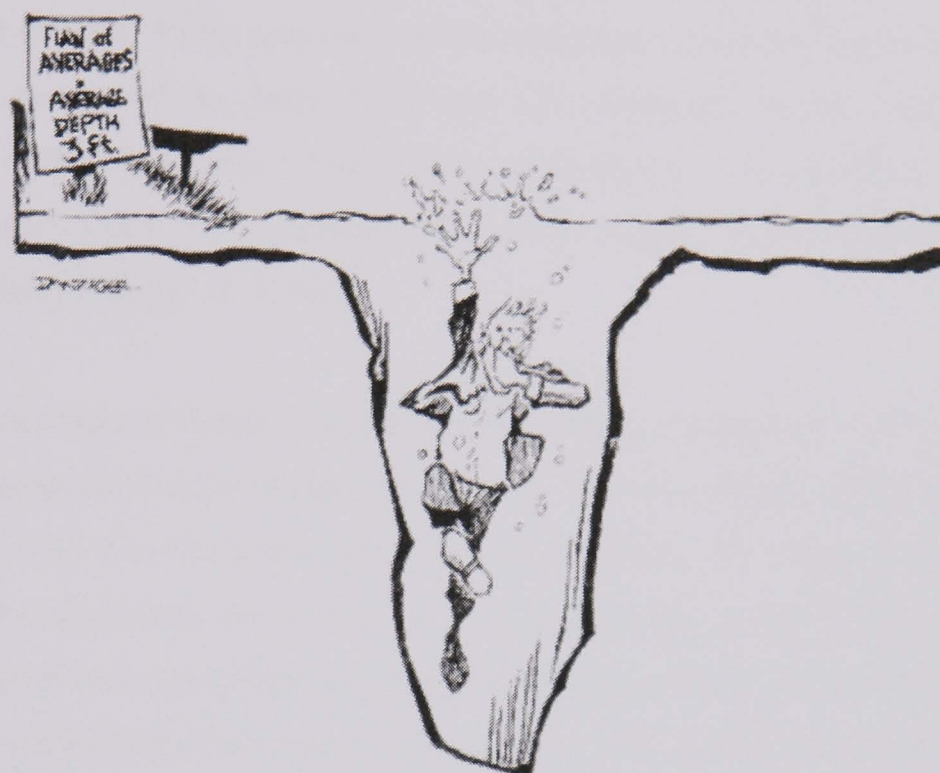


Figure 7.1: The Flaw of Averages: by Jeff Danzinger (from <http://analycorp.com/uncertainty/> on 14/09/02)

It is clear then, that given the uncertainties that remain, even with the most sophisticated methodologies for risk assessment, that new approach is required that brings together both quantitative and qualitative data, to assist decision-makers in bringing together specialist knowledge and opinion in order to support decisions.

The goal of this research then is to test, through the use of a case study, whether the CMAM work can meet all these varying demands and to develop a methodology for organisations to follow in order to get the most out of this new body of research. This theme will be developed further through subsequent chapters.

7.4 The history behind the CMAM work at the University of Bristol

The research project, known as CMAM (Condition Monitoring and Asset Management), headed up by Dr Jim Hall, follows on from a stable of research into supporting decisions relating to complex infrastructure systems where data is extremely sparse and not particularly reliable. The research deliberately did not set out with the brief of improving or extending previous work, but clear parallels with former projects were exploited to ensure maximum efficiency.

The “Italian Flag method”, coined by Blockley and Godfrey in their book “Doing it differently – systems for rethinking construction” (2000), which was written in response to The Egan Report (DETR, 1998) criticisms of the construction industry, drew on work in the Juniper project, conducted by John Davis and his colleagues in the Civil Engineering Systems Group at the University. The Juniper methodology was originally developed in response to demands from the oil industry for tools to support decision-making when very little data is available (Hall *et al*, 1998).

An example of this type of decision is the case of drilling exploratory wells. Clearly, this incurs a certain amount of expense (and other risks), and thus should ideally be undertaken in the situation where it is likely that some oil will be found. However, paradoxically, the whole reason for undertaking the drilling is to determine for certain whether or not oil is present. The Juniper tool is essentially a method for using qualitative techniques (e.g. expert judgements) for supporting these types of decisions, where quantitative data is not readily available, or prohibitively expensive to obtain.

The methodology involves experts working together in small groups to quickly produce hierarchical models of the decision space. The idea is to overcome the issues of “silo” thinking that have been touched upon in this and previous chapters by viewing the system in question as a series of interconnected processes. There are three essential features of systems thinking (Blockley and Godfrey, 2000). These are holons, connectivity and a new whole view of process.

The word ‘holon’ relates to the idea of a holistic approach; one that manages the complexity and competing demands placed on a system. Koestler originally defined the word in 1967 when the holon became a fundamental building block of systems thinking. The concept followed in the Juniper project and carried through into the CMAM research was that every system is a set of interacting holons. Each holon is a complete process in itself, but can be broken down into other holons, each of which, at any particular layer in the model, should be described with a similar level of precision of definition (Blockley and Godfrey, 2000). It is important (as will come clear in future chapters) that the holon is described as a process, rather than an object, however, the examples that are given are frequently objects so that the idea can be clearly understood. Blockley and Godfrey (2000) give the example of the human body as a holon, which contains several sub-systems that are holons in their own right (e.g. the skeleton is the structural holon; the nervous system is the information holon; and the blood circulation is the internal energy distribution holon). Some thinkers have attempted to

use this analogy of the human body to develop a generic holon (Sanchez-Silva, 1995). This idea of the generic holon is discussed in greater detail in Chapter 8.

The last decade of research at the University of Bristol has shown that the connectivity between processes is very important (see for example, Cui and Blockley, 1990; Hall, Blockley and Davis, 1998). The concepts of necessity and sufficiency (Blockley and Godfrey, 2000) are logical but very difficult to convey mathematically. The idea is that while a higher-level (or parent) process holon is made up of lower-level (or child) process holons, these “children” do not all have the same effect on the parent process. Looking back at the body analogy, it could be argued that sight, speech, touch, hearing and smell are all part of some parent holon such as “interacting with outside signals”. However, depending on the individual in question, some of these senses might be more important than others. A musician, for example may have an auditory or visual preference (hence the expressions of being “good at sight-reading” or finding it easier to “play by ear”). It is therefore possible to determine which child processes are necessary for the success of the parent and which might be sufficient, as well as those that are neither necessary nor sufficient (Blockley and Godfrey, 2000). The issue of demonstrating necessity and sufficiency through mathematics formed a major part of the CMAM research and was still being debated after the official close of that project.

Prior to CMAM, the “Italian Flag method” was used to capture expert opinions of the performance of holons in a system. Each holon comprised a text description and an “Italian Flag” of performance. The “Italian Flag” is based on ideas taken from Interval Probability Theory (IPT). In classical probability, if one were to throw a coin and give the “odds” that it would land head face up, most people would say that the chance was 50% (and the same for heads). If landing with heads face up was considered success, and landing tails up is failure, then this could be represented as follows, where green is probability of success and red is probability of failure.



Figure 7.2: Traditional view of probability

With Interval Probability it is possible to demonstrate that there is some uncertainty in these values. Taking the coin toss example, there is a small chance that the coin may land on its side (or, to take it to an extreme, that it may never land at all). Thus, the probability of

success and of failure remains equal (assuming an unweighted coin) but there is a small chance that neither of the expected outcomes will occur. This is represented in Figure 7.3.

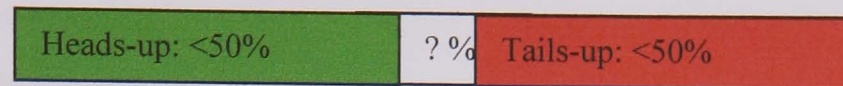


Figure 7.3: Acknowledging uncertainty using Interval Probability Theory

Prior to CMAM, these ideas were used, successfully, for facilitating decision-making in groups by adding qualitative assessments of the amount of red, green and white that should be present in the flag for each process holon. The level of evidence can easily be adjusted, but only on sub processes that are not further sub-divided, in other words, those that are at the bottom level of the hierarchy (Anderson and Jenkin, 2002). Nonetheless, even with this limitation, the method has informed decisions and provided a record of how these decisions were made, which is an important step on the road towards more advanced Asset Management (Cui and Blockley, 1990; Hall, Blockley and Davis, 1998). An anecdotal explanation of the use of IPT (Interval Probability Theory) in this context can be found in Blockley and Godfrey (2000). In the CMAM research “The Italian Flag” was referred to by the more formal term of Figure of Merit.

The downside of the methodology as it stood in 1999, was that it did not allow quantitative and qualitative data to be brought together in the same framework. Indeed, as has been identified in the previous chapter, there is a general lack of techniques that allow the decision-maker to compare the “apples and pears” of real-life information. Recent research (Sánchez-Silva, 1995, and Le Masurier, 1999) has identified the need for supporting decisions using logical frameworks (and hierarchies), populated with quantitative and qualitative data, but the aim of the CMAM project has been to develop these ideas still further, to come up with robust “decision support techniques to improve the safety and economic performance of complex civil engineering infrastructure systems” (Hall *et al*, 2001).

7.5 Possible Benefits of the CMAM methodology

The CMAM methodology, of which the author is a co-collaborator, claims to offer several benefits to those people charged with making decisions relating to complex infrastructure systems. The key benefits that were hoped for, and which are tested throughout the remainder of this thesis, using a case study based on Scottish and Southern Energy plc, are:

- An increased understanding and better communication of risk and uncertainty throughout all levels of an organisation;

- Rational commissioning of surveillance and monitoring, with more effective use of subsequent data;
- More economical asset management, based on clear, robust models supporting decisions;
- Auditability, traceability and transparency of decision-making, allowing for continued learning and transforming expert opinions into reliable judgements;
- A new understanding of the processes within an organisation, allowing old “silo” thinking to be bypassed for more efficient, interconnected ways of working;
- Prevention of objectives “falling between the interfaces”, as people within different departments, with different ‘views of the world’ (e.g. financial experts, engineers etc.) are able to communicate more clearly, using the same process model ‘map’ of the organisation;
- The capability to estimate the current performance of the company (benchmark) and test various scenarios for improvement;
- A clear understanding for all those within the organisation of the importance and significance of collecting certain performance indicator data;
- A methodology for justifying decisions to reduce spending on monitoring or other actions in one part of the organisation, in order to improve performance across the company;
- The ability to demonstrate to the HSE and other regulators, that risks are being brought into line with the ALARP philosophy; and
- A base for investigating ISO 9001:2000 ideas relating to process modelling in relation to assuring quality.

It soon became clear, during the process of developing the methodology, that the process of building the hierarchical models on which the rest of the system is based was not trivial. Indeed, as much of the learning about the system in question resulted from the actual process of constructing the model and assigning criticality values (sufficiency and necessity, which will be discussed in more detail in Section 7.6) as from viewing the completed system model. John Davis, who was a key member of the project team, had experienced this when undertaking Juniper modelling exercises in the oil sector (Davis and Hall, 1998).

7.6 Key Principles of the CMAM methodology developed at Bristol

The core aim of the CMAM methodology is to support decisions where information is of varied quality and type, physical processes are complex and difficult to predict, and where

data is scarce. It must support expert opinions and debate, so that traceable and reliable expert judgements can be made.

The research group to which the author contributed has identified eight key principles for informing Condition Monitoring and Asset Management decisions. These are (Hall *et al*, 2002 & 2003):

1. The infrastructure system of interest is described *hierarchically*.
2. The hierarchy is constructed by considering the *processes* that the system enacts.
3. *Performance Indicators (PIs)* are drawn from data assembled from all available sources, even when the measurement is uncertain, expressed linguistically, the record is incomplete, or data from different sources appears to be contradicting.
4. Performance targets are expressed as *value functions*, which map from the (usually dimensional or linguistic) scale of the particular PI to a non-dimensional scale of performance relative to objectives.
5. One or more value functions can be combined for any system or systems and sub-system in the hierarchy to produce a *figure of merit*; a non-dimensional measure, on a 0 to 1 scale, of how the system is performing against objectives.
6. The figure of merit is calculated by assessing evidence of performance from either or both of two sources:
 - a. PIs *propagated* through the model from sub-systems (holons) that are below the system of interest in the hierarchical system model; and
 - b. PIs associated *locally*, at and with the system of interest.
7. *Uncertainty* in performance indicators, value functions and figures of merit is handled explicitly.
8. Asset managers can examine specific aspects of performance, for example cost, safety or environment, as well as the overall performance of the system, by weighting particular PIs according to how much evidence they contribute to the understanding of each particular performance aspect.

These key principles are discussed in detail in the following sub-sections.

7.6.1 Hierarchical model of processes

Given the proliferation of “process modelling” ideas and systems that have appeared on the market (even during the three years of this research) it is important to clarify what is meant by a process model in this context. The models required for the CMAM methodology are hierarchical and follow the systems rules given in Blockley and Godfrey (2000). Essentially,

the definition of the process is an action that transforms some input into an output. However, unlike the IDEF family, the inputs and outputs are not explicitly demonstrated on the model. Thus, it begins to become clear that the CMAM model is not intended to be used as the basis of a workflow system, a knowledge management system, nor a business information model.

These systems would facilitate mapping between specific activities, personnel, information and other resources required. Simply entering the word “process model” into a search engine on the Internet will result in a number of these business management systems being identified. Some of the best of these, such as HardCat can be used to manage an entire business, combining stock control, purchasing, barcoding, maintenance and workplanning, depreciation and cost prediction modules into one integrated asset management system.

The CMAM model is not designed to go into this level of detail, although the key attributes (such as process owner) of each process can be added as desired. The research aim has not been to develop a workflow description to be used to *manage* processes, but rather is a snapshot overview of the *performance* of the system at a range of levels of resolution. Thus, great benefit may be achieved in the future by linking models created in Perimeta (the new name for the tool developed during the CMAM project) to the enterprise and asset management systems that are now available.

The CMAM tool supports a hierarchy in the form of an acyclic graph, rather than being a strict tree structure. In other words, each child holon can be connected to more than one parent. The only constraint on the model structure is that it must be hierarchically layered with links connecting each holon at the top or bottom (not the vertical sides or corners).

In carrying out this case study and in further work since, the author has identified a number of practical difficulties that are raised rather than solved through the use of this “upward” multi-connectivity. This is discussed in more detail in later chapters.

7.6.2 *Assembling Performance Indicators*

Simply constructing a process model of part or all of an organisation is a worthwhile exercise. As the case study and further work described in this thesis will demonstrate, this is no trivial task and yet can produce some immediate and important results. For example, it soon becomes evident where the organisation is lacking processes (frequently at the tactical rather than strategic or operational (or job/performer level, after Rummler and Brache

(1995)) or is missing links between processes that would make the system much more efficient and effective.

However, the power of the CMAM methodology, which the author has begun to exploit more fully as part of the Performance Improvement Cycle approach described in mentioned in Chapter 10 and described in Appendix D, is that it enables an organisation to gain a view of how it is performing. This can be visualised by the Figure of Merit (see Section 7.6.4) for a particular holon, or for an entire system by viewing the effect on the highest holon that occurs as evidence is propagated up the hierarchy. This is why, as the methodology described in this thesis explains, it is useful to have the top-level holon representing the overall mission or goal of the organisation, so that the current level of overall performance against the stated service outcomes can be determined and monitored over time. In addition, this “summing” effect is useful for testing the impact that various scenarios would have, through their effect on locally measured evidence, on the performance of the system as a whole.

“Performance: The act of performing; the carrying into execution or action; execution; achievement; accomplishment; representation by action; as, the performance of an undertaking of a duty”

(Webster, 1998)

Since performance can be defined as the undertaking of a duty this gives an image of a system carrying out some action that meets the demand being placed on it. For an organisation, this demand may appear differently at different levels and parts of the system. However, as the case study demonstrates, what is actually occurring is that a high-level demand (or duty), which is normally the mission or vision of the organisation, is translated through the various levels until it reaches the appropriate level of detail and granularity for action to be taken. This is in line with the thinking of Advanced Asset Management (IAM, 2002).

As can be seen from the dictionary definition given above, performance must always relate to something. It can be described in terms of a particular aspect of desired performance, such as safety, cost or sustainability; or can refer to performance against specific targets. Performance must always be *in relation to something* – it cannot stand alone. This observation has an interesting outcome. That is, it soon becomes clear that one performance indicator (PI) can actually shed light on more than one type of performance. For example, “tons of paper used” might, depending on context, relate to the performance of an organisation in terms of *turnover* (if the company is a publisher), *running cost* (for a consultancy producing reports) and/or an *environmental* parameter.

Performance is sometimes measured in terms of compliance with or deviation from a performance standard. While it is true (Senge, 1990) that the important performance standard is that which satisfies the customer, the use of prescriptive “standard” levels is not always helpful. For example, as Deming (various) teaches, even when a standard is met, deviation within the acceptable limits can be unhelpful as it may require adjustments when one or more components (or processes) are brought together. The CMAM methodology gives an opportunity to overcome this “pass/fail” culture that is characteristic of traditional engineering thinking. Therefore, the setting of performance standards (such as the serviceability and ultimate limit states) can be complemented by an understanding that performance is a continuum. This is elegantly expressed through the use of value functions, which are discussed in the next section.

The system being modelled will have various types of performance indicators associated with it. Each performance indicator is a form of measure of performance. In accordance with meeting the need identified earlier in this chapter, such indicators can take various forms, from physical measurements (e.g. amount of settlement, width of crack), outputs of statistical failure mechanism, deterioration and finite element models, through to the linguistic judgements of those reporting on the condition and performance of the assets. Each of these types of evidence can be expressed through the seven generic value functions described in the following section.

Monitoring information can often be scarce and expensive to obtain and the CMAM methodology aims to include as much of it as possible by not specifying a particular format for data collection. Therefore, there is no need for all data to be in, for example, a probabilistic format. Instead evidence is assembled from all available sources and may comprise “hard” sources, such as monitoring measurement, failure records, design calculations and model studies as well as “softer” ones, such as inspection records, expert judgement, records of analogous cases and accounts of past failures. Predictive indicators can also be derived from current monitoring activities, mathematical models of future behaviour and failure or fragility curves. “Harder” PIs, which can be captured numerically, are handled through the six quantitative value functions (Figure 7.4), while others, expressed by linguistic statements (e.g. “very poor” or “good”) can be mapped through the qualitative function (Figure 7.5).

There will be a range of “granularity” of performance indicators. That is to say that some will be very high level, relating, for example, to the profitability of the organisation, market

share, customer performance, safety or some other key indicator of the systems overall performance against its stated mission and vision. Going down through the hierarchy the PIs will become increasingly detailed and will relate to smaller and smaller parts of the organisation. An example of a lower level PI might be the number of “failures to start” of a particular piece of plant or equipment.

Some holons within the hierarchical model may not have performance indicators (PIs) associated with them (which demonstrates areas of the systems where decisions are being made on the basis of ‘hunch’ or ‘history’ rather than best practice), while others may have several PIs giving an indication of their level of performance. Part of the Performance Improvement Cycle that the author has been developing since completing the initial period of research includes a step focusing on producing a cascade of performance indicators to ensure that performance is measured appropriately at each holon and level of the system where it is required. In some cases it must be recognised that there is no need to associate formal PIs to a holon, but instead to rely solely on a professional opinion alone to assess the performance of the process. This is clearly only acceptable in cases where more formal PIs are not available, and, because of the low weighting on the holon, monitoring resources would be better spent elsewhere to reduce the overall risk to the system.

In some cases the most appropriate PI to monitor may not be measurements but the rate at which they change, or any acceleration in their change. By storing time series of PIs these rates of changes or higher derivatives can be extracted. In addition, the original data should be preserved for analysis and interpretation as necessary (Wheeler, 1993). This is also important because many PIs that are currently reported will have been processed before viewing. An example of this would be a key PI used in the hydro-electric sector, which is the average age of plant. This is used as an indication of the current reliability, condition and remaining life (and future investment) that is required. Once averaged into one “global” PI for the whole company, there is a danger that some of the key information can be lost (Deming, various). A more detailed discussion relating to the time-varying nature of PIs and the extent to which the CMAM methodology, as it stands is equipped to support this, is given in Chapter 10.

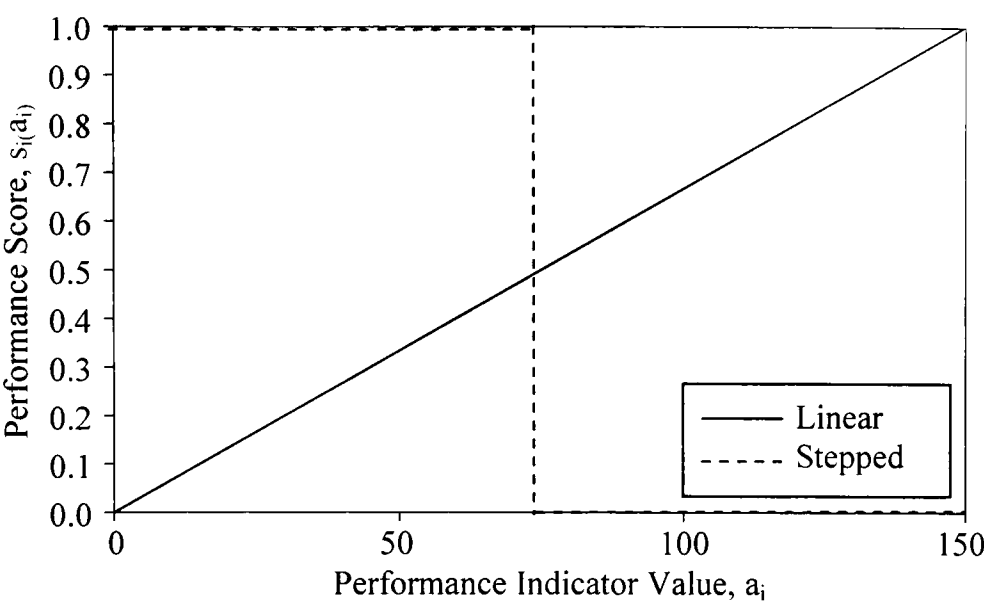
Ideally all the PIs should be stored within one corporate database, however, the CMAM research team realised early on that the methodology would be of little practical value if, in reality, it required new data management systems to be adopted. Consequently, this was taken into consideration during the development of the CMAM software. The latter is designed and written in such a way, using XML (Gulbransen, 2000), so that it can be adapted

to extract information from existing data sources, rather than requiring ‘double entry’ and copying across of data from existing databases. Increasingly organisations are developing data warehouses (Turban and Alonson, 1988), which, through the use of an SQL query code generator, natural language query system, or automatic form builder enhance the ability of users to access needed data. With the advent of mobile technology in the form of PDA’s and tablet PC’s, the “field” to “query” time should continue to decrease, leading (with proper management and discipline) to increasingly up-to-date data being delivered to the user.

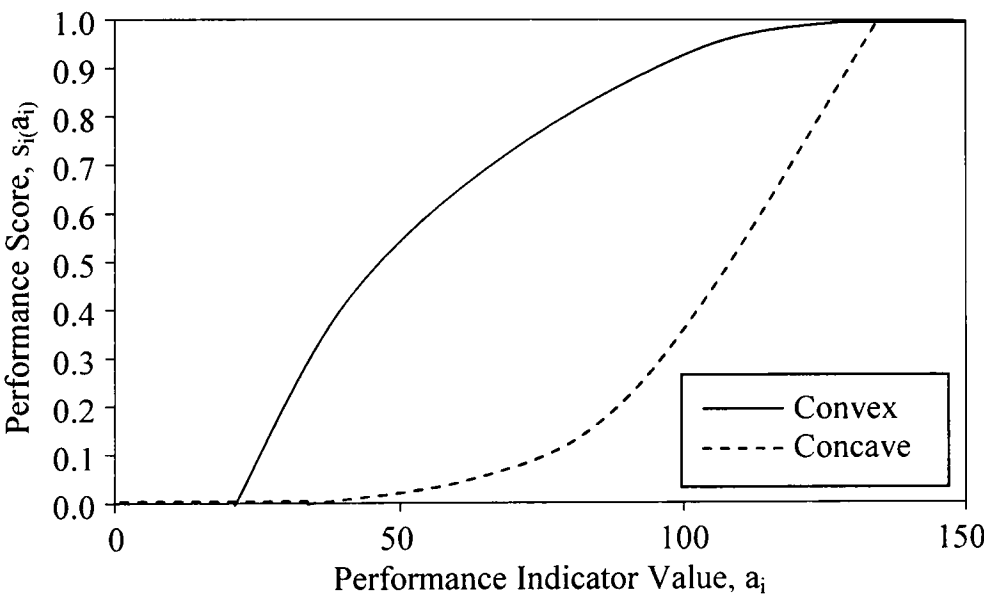
7.6.3 Mapping Figures of Merit from Value Functions

In order that all PIs can be managed together to provide an enriched understanding of the performance of the system, value functions are used. These convert the PI from its existing scale (usually dimensional or linguistic) onto a non-dimensional scale, which ranges from 0 (failure) to 1 (desired performance). In the CMAM methodology there are seven generic different types of value function that can be adapted for each PI. The six ‘numerical’ functions are shown in figure 7.4, while the special case ‘linguistic’ function, can be seen in figure 7.5.

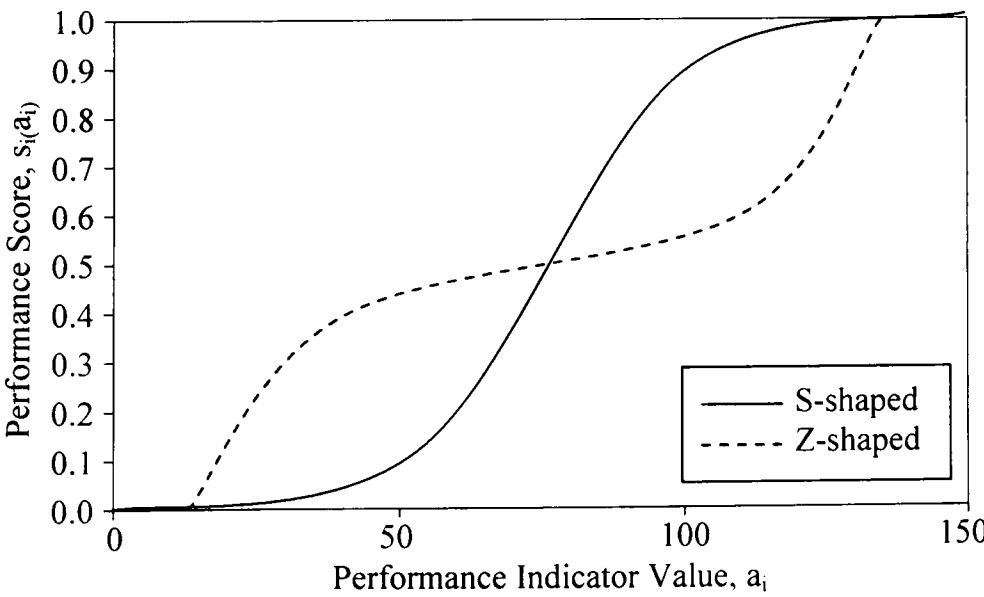
This method of mapping a performance indicator to a performance score is not new (French, 1988; Wymore, 1993). In fact, the Riggs matrix (Dervitsiotis, 1999) achieves a similar effect. The methodology (the matrix) requires the user to input 11 reference points that relate the PI to the performance score (from 0 to 10). However, the use of three points is also common. The idea is to use the performance score (y-axis) to peg the organisation’s current performance against best practice. Thus the PI value equating to performance of 10 is the best-in-class or “stretch” goal, determined from a benchmarking study. A score of 5 equates to the industry average, while 0 might correspond to a company that is on the point of failure (due to inability to satisfy customer service, quality or cost demands).



a) Linear and Stepped



b) Convex and Concave



c) S-shaped and Z-shaped

Figure 7.4: The six generic “quantitative” curves

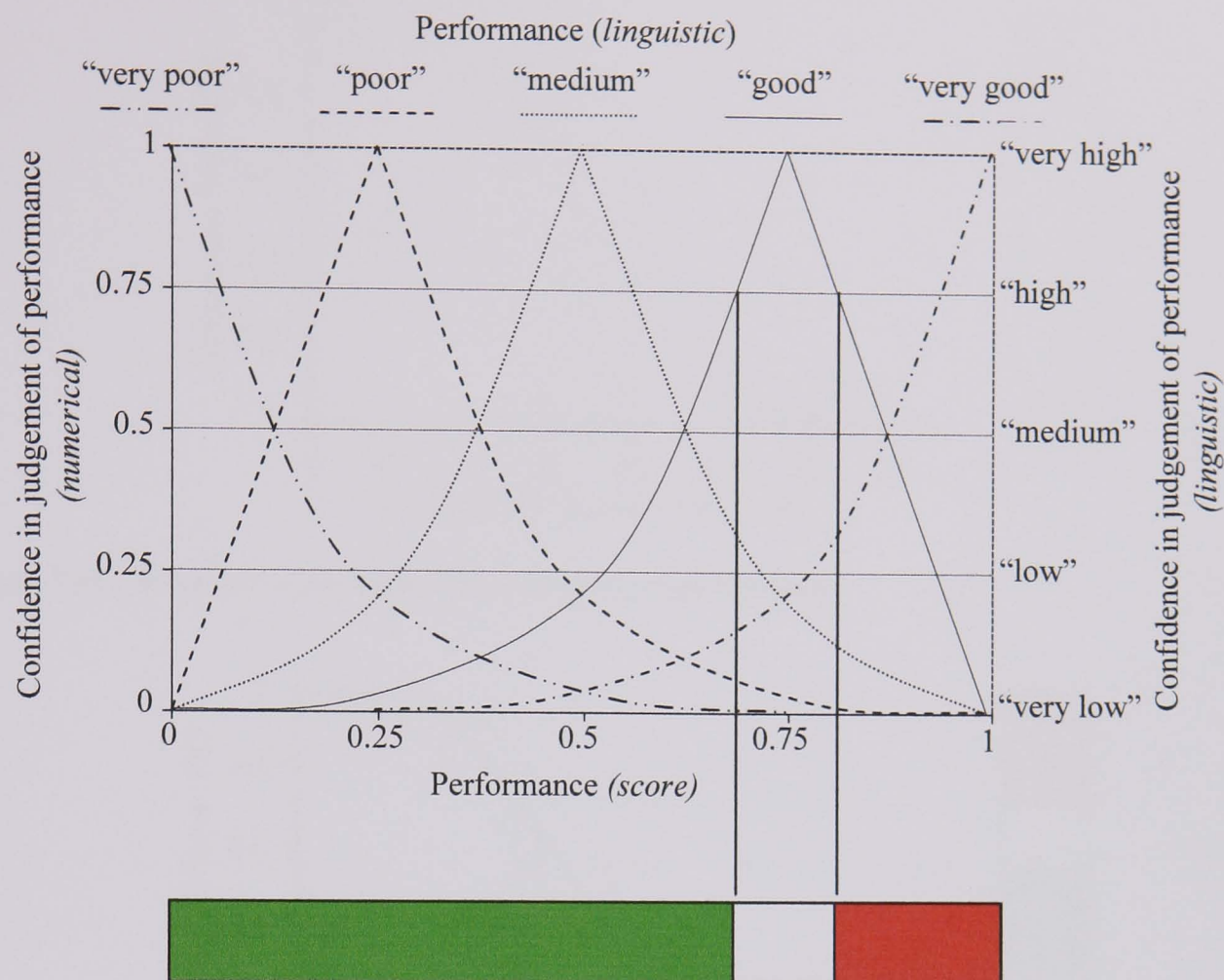


Figure 7.5: Mapping linguistic descriptions of performance, and the confidence in the performance assessment onto interval values of probability

The key advance with the CMAM methodology is that it takes into account the uncertainty inherent in producing the value function. Instead of a one-to-one mapping, a particular PI value translates into a Figure of Merit (Interval of Probability) “score” as described in Section 7.4.4. This is not only true for the linguistic function (Figure 7.5), but also explains why the small number of generic value function shapes (Figure 7.4) is logical, because further precision cannot be justified. This is clearly true when one considers that there are two main sources of uncertainty:

- The correct shape of the value function; and
- The exact value of the performance indicator.

The first uncertainty is that associated with expert opinion. Of the group of experts choosing the value function in Figure 7.6a, the average view is that excellent performance (PS = 1; point A) is retained until the PI reaches about 20. Poor (failing) performance, the group believe, is reached at some PI value of 110 to about 120 (point C). However, the group’s uncertainty has the greatest impact at about the average score (PS = 0.5, point B), which some feel reflects a PI value of about 60, while others feel that this level would not be reached until about 80 (Figure 7.6a).

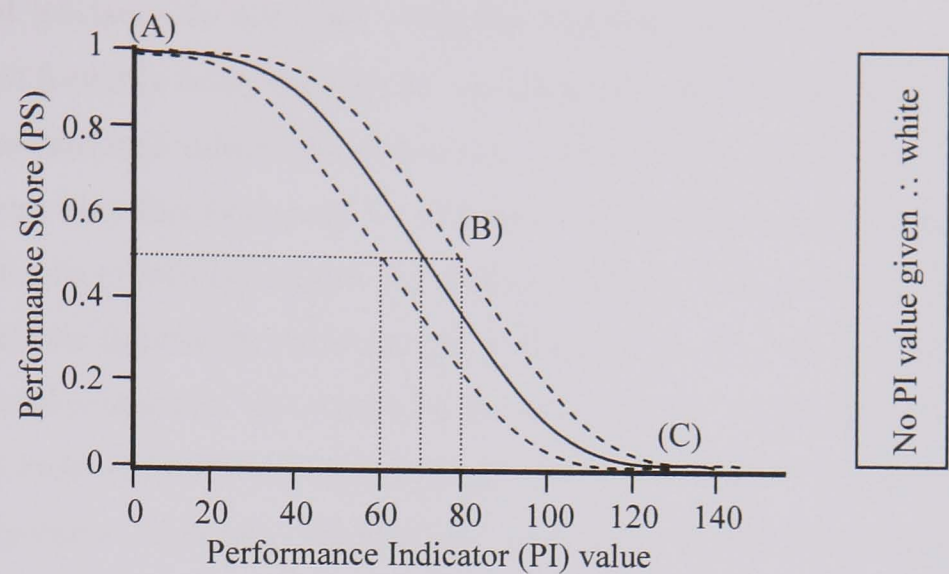


Figure 7.6a: Example of an uncertain S-shaped value function

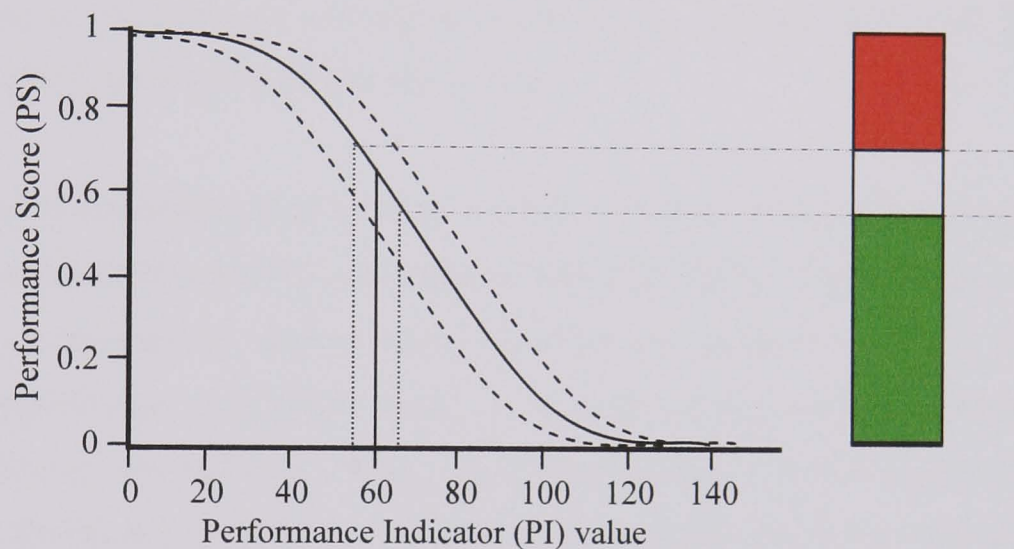


Figure 7.6b: Example of an S-shaped value function with uncertain PI value

Figure 7.6b gives an example of uncertainty regarding a PI value as well as the value function shape. The current value is thought to be 60, give or take 5. It is interesting to note the amount of white that this adds to the Figure of Merit.

The choice of value function that is used to transform the performance indicator onto a scale of 0 to 1 depends on the judgement of those inputting the data. Where regulatory and code of practice guidance exists, the value functions will reflect this. For example, a stepped function might be used where a particular threshold dictates the limit of acceptable performance. However, stepped functions are generally replaced where possible with an S or inverted S-curve because this takes into account the fact that there is some uncertainty relating to performance near the threshold. Thus, decision-makers can make an informed decision to balance risk with potential savings, by taking a chance and going slightly over certain boundaries, where that risk-taking is appropriate.

Where external guidance is not used, company standards may be used, or, where such standards do not formally exist, the experts inputting the value functions must adapt them to reflect the organisational values and objectives. Where these exceed the requirements of regulation, more value functions may be adapted to reflect the more stringent performance criteria. Dervitsiotis (1999) insists that the shape of value functions and the weighting given to each PI should be decided by management, since they are most familiar with competitive and environmental conditions. He states that the task must not be delegated to technical staff and that, while facilitators and consultants might be able to assist they are no substitute for managerial judgement. However, because the case study, described in this thesis, involved analysis of technical PIs the author chose to ask experts with the relevant experience to formulate the value functions. The use of quality teams comprising staff from all levels and several divisions of the company can help to minimise any risk of either global managerial, or detailed technical factors being excluded in error.

The second area of uncertainty that has been touched on above is that of the current value of the PI, and, once scenario testing is attempted, of the future value of the PI. This uncertainty can be due to a number of reasons, some of which are easier to quantify than others. Examples of quantifiable uncertainty would be in cases where statistical estimates of the bounds of uncertainty can be made: when there is missing data; a limited sample set; or some other cause of statistically quantifiable uncertainty. However, there are other cases where the uncertainty cannot be accurately estimated; for example if a particular person undertaking monitoring makes occasional mistakes, or has faulty equipment. This risk can be minimised by following the principles of Statistical Process Control (Wheeler, 1993; Deming, 1986,1994).

In effect, these value functions act as knowledge representations. This idea has a long history, particularly within the medical sector. For example, in the 1970's Dr Edward H. Shortliffe of Stanford Medical School developed what is thought to be the first example of a classic expert system (Turban and Alonson, 1995) to help doctors diagnose bacterial diseases of the blood (such as meningitis) and prescribe the correct treatment rapidly, since early diagnosis and treatment are essential in such cases. The system used rule-based knowledge representation in the form of IF-THEN inference rules. Some of these were quite detailed involving a series of AND statements, such as:

IF (1) The infection that requires therapy is meningitis, and (2) the patient has evidence of serious skin or soft tissue infection, and (3) organisms were not seen on the stain of the culture, and (4) the type of infection is bacterial THEN There is evidence that the organism (other than those seen on cultures or smears) that might be causing the infection is Staphylococcus coagpos (0.75) or Streptococcus (0.5).

Because the CMAM approach is not designed to make decisions or suggest causes but instead to facilitate decision-making by supporting experts in recording the available information in relation to performance, the “rule-base” is not so desirable.

In fact, the CMAM use of value function has some of the same advantages of rules while avoiding the common disadvantages. The advantages include (Turban and Alonson, 1995):

- Value functions, like rules are easy to understand and are communicable;
- Inference and explanations are easily derived (particularly if the commentary function of the Perimeta software is used);
- Modifications and maintenance are relatively easy (particularly once the model is implemented in the tool);
- Uncertainty is easily combined with the rules (this is especially true for the value functions used in CMAM, where the uncertainty is explicit as “white” in the Figure of Merit); and
- Each value function can be handled independently of all others.

One of the major disadvantages of rules (Turban and Alonson, 1995) is that complex knowledge often requires thousands of rules, which creates difficulties in building and maintaining the system. Because the CMAM approach aims to demonstrate performance and thus assist in decision-making (rather than diagnosing) the number of value functions required depends only on the number of performance indicators to be considered. If, as suggested in Chapter 8, these performance indicators are rationalised prior to implementation, then this should not be an overly onerous task.

In addition, value functions provide a flexibility that is not associated with rule-bases. For example, the value function shape can be slightly different for different areas of the same company. Thus, a curve linking generation to performance would be a different shape for different generation sets.

Another danger of rules is that system builders are comfortable with them and may try to enforce all knowledge into rules rather than looking for more appropriate representations. In the case of value functions, it is evident which information is appropriate to be handled in this way, which is why the system is not in itself a work-flow or knowledge management system but can be used to support such a system once the performance is properly understood.

However there is one disadvantage that the value function methodology shares with rules and this is that, because of their versatility, there may need to be a large number of rules (although there is only one generic value function for each performance indicator, local versions, as described above, will rapidly increase the size of the performance indicator database). This is managed by incorporating a search facility for finding performance indicators and their associated value function(s) in the performance database in the Perimeta tool.

It is essential that the people who choose the appropriate value function are those who are able to inform the decision. They must be experts in the field in question, not consultants brought in for the task who only have a limited understanding of the technical issues involved (Dervitsiotis, 1999). The experience of those who have worked on assisting decision-makers in coming to conclusions in past projects (Davis and Hall, 1998) reveals that the most appropriate and robust way of determining the desired value function is for a team of experts to work together to come to some agreed understanding. During the workshops with the steering group for the CMAM project this technique was tested and found to be workable and considered to be of value by those experts who participated.

7.6.4 *Weighting and Propagation*

Once each PI has been projected through a value function, it can be weighted according to the extent to which it is felt to contribute an understanding to the overall performance of the holon in question. The weighted PIs are then combined at the local level to generate a figure of merit for each holon. These figures of merit, described in Section 7.6.3, can also be influenced by value functions that propagate up through the system from lower in the hierarchy. The balance of propagated and locally entered data is also determined through the assignment of an expert-agreed weighting. The sixth principle of the CMAM methodology is again a step forward from the Juniper work. It allows the figure of merit for any given holon to be calculated by assessing evidence of performance from either or both of two sources:

- PIs *propagated* through the model from sub-systems (holons) that are below the system of interest in the hierarchical system model; and
- PIs associated *locally*, at and with the system of interest.

While evidence for performance can still be entered directly at the bottom level of the hierarchy (Anderson and Jenkin, 2002) it can also be entered locally at any holon (not just the bottom level).

In addition, PIs are also propagated up through the model from child holons to their parent, all the way to the top of the model. This has the great advantage that it is therefore possible to give an indication of the overall performance of the system. The weighting between the locally entered PI and the propagated value can also be changed. For example, if a lower level PIs are felt to be incomplete a higher-level PI might be given more weighting. Alternatively, on many occasions, high level PIs are not available, and thus no local evidence is available and the decision maker must rely only on propagated evidence to that level. The holons at the bottom of the hierarchy will only have locally entered evidence, but all other holons will have propagated evidence and may also have locally measured evidence.

The method for propagating the evidence through the hierarchy has been the subject of a good deal of research and debate. The reason that this is such a complex area is that the evidence being propagated is essentially an interval of probability, rather than a point value (as would be used in the Riggs Matrix methodology described by Dervitsiotis in his 1999 paper).

In the original CMAM methodology, which was completed in 2002, the propagation of evidence was achieved using the uncertain inference mechanism of Interval Probability Theory (Hall *et al*, 1998). The methodology described in the 1998 paper, published by the CMAM research group was based on the idea that the Figure of Merit could be interpreted as a measure of belief in the hypothesis that the given holon is behaving satisfactorily. That is to say, if the subjective probability (of the hypothesis being true) was $P(H) = 1$, the Figure of Merit would be completely green, with no uncertainty or incompleteness in this judgement that would represent 100% success; there would be no doubt in the modellers' minds that the holon was successful. Of course, in reality there would be some uncertainty in this assessment, which is why the interval allowing an area of white in the Figure of Merit was found to be so powerful. Other researchers, also battling with the idea of supporting reasoning with uncertainty due to vague or incomplete evidence had criticised the previous use of Bayesian theories of probability because they fail to manage this challenge (Henkind and Harrison, 1998; Shafer and Pearl, 1990; Krause and Clark, 1993).

The idea of propagating an interval of probability is founded in the mathematical theory of evidence (Shafer, 1976; Klir and Folger, 1998). The research team elected to use what appeared to be a relatively straightforward approach to evidential reasoning, called Interval Probability Theory (IPT) (Cui and Blockley, 1990; Hall *et al*, 1998) which had the following perceived advantages over conventional Bayesian approaches:

Probability Theory (IPT) (Cui and Blockley, 1990; Hall *et al.*, 1998) which had the following perceived advantages over conventional Bayesian approaches:

- Ability to capture aspects of fuzziness of data through the use of hierarchical knowledge structures;
- Relatively straightforward representation of causes of uncertainty; such as ambiguity, conflict, randomness and incompleteness;
- A balance between overly weak inferences, which would result in little insight being gained, and of overly strong inferences, which could give the impression of more certainty than is in fact the case;
- Convenient representation of dependency relationship between evidence; and
- Capture of range of inferential relationships between levels in the evidence.

The method, due to its mathematical pedigree, had a further advantage over the heuristics employed in the original Juniper methodology; that of being accepted by peer scrutiny. However, as it has transpired, there were issues with the use of IPT in this context that took more time to be resolved than had been expected. These will be discussed in the last section of this chapter. At the time of writing, the current version of the software, Perimeta, has been built with a choice of the old-style Juniper algorithms and the revised CMAM algorithms. Further studies are currently underway to test, validate, and compare both methods and to provide user guidance regarding the optimum application for each method.

Regardless of which method is used, the propagation between child and parent holons is always in the direction of the top of the hierarchy and is expressed in terms of *necessity* and *sufficiency* (Hall *et al.*, 1998, 2001, 2002a, 2002b, 2003). In the context of performance modelling in systems, necessity and sufficiency can be thought of as follows:

Sufficiency is a measure of the amount of influence a given sub-system has on the performance of its parent or super-system.

Necessity is a measure of the extent to which failure (non-performance) of a sub-system will cause failure (non-performance) of its parent system.

Broadly speaking necessity can be thought of as being related to failure or poor performance whereas sufficiency is related to the positive contribution that a child holon makes to the successful performance of its parent. Unfortunately, it is not true to suggest that the sufficiency is a “weighting on the green” and the necessity a “weighting on the red”. Mathematically and pragmatically, the problem is more complex than this. The author has found, in work completed following the initial period of research described in this thesis, that

wishing to use the CMAM methodology. This is one of the barriers to take-up identified in Chapter 10.

Further complexity is introduced when one considers the fact that two or more child holons are unlikely to be truly independent of one another. If this is not taken into account, it could bias the view of the performance of the parent holon. Therefore, a concept of *dependency* is introduced in the CMAM methodology (see Hall *et al*, various). The dependency can be interpreted as being due to evidence originating from a common source or being influenced by a common process. An example of a common source would be one person reporting the information, or data stored in one database (which may have a consistent error). Other influences might include “double-counting” of the type where one element of performance (such as age) might naturally be thought to correlate with another (such as condition). The concept of dependency has been developed (Cui and Blockley, 1990) to help to avoid any over- or under-estimations of performance that could result from such “double-counting”.

7.6.5 *Aspects of Performance*

As has already been touched upon in Section 7.6.3, there may be several aspects of performance that are of interest to the decision-maker. In some cases, the same performance indicator may be mapped through more than one value function to provide a different figure of merit for each aspect of performance. For example, the PI “frequency of inspections” would be valued differently if it was considered in light of the likely reliability or safety of a particular asset than it would be if considered with regard to financial performance. These issues are seldom clear cut (particularly where financial concerns are considered) because the ‘knock-on’ cost of unreliable performance could ultimately outweigh that of increased monitoring. The CMAM methodology was never intended to be a tool for carrying out whole-life cost analysis, but, through the use of different value functions for one performance indicator, these conflicting views of performance can be brought to light.

In addition to one PI being interpreted in more than one way, there is also the case where one holon has several PIs associated with it. In this case, the CMAM methodology can capture some of the subtleties that are faced by those trying to make decisions about the system by allowing the user to weight each one before it is associated with the holon. Thus, a PI relating to safety might be given three times the weighting as one relating to cost, and twice that of one associated with performance with respect to the natural environment.

As well as weighting different PIs according to relative importance in the “Overview” view of the model, and using different value functions to translate one PI into several figures of merit, there is one more way in which the CMAM methodology allows the user to visualise performance. It is possible to take a “slice” through one aspect of performance, such as safety, cost or the environment. This is done by producing a duplicate version of the “Overview” model and:

- changing weightings on links; and/or
- changing the weighting of individual PIs associated with a holon.

The method of changing weightings on links is comparatively crude. Essentially, what this allows is for a particular process that is clearly associated with the aspect of performance in question to be given a higher relative importance to the parent holon than other children on that level. This is done by adjusting the necessity and sufficiency values that control the propagation of this child’s evidence through to the parent, and on up through the hierarchy.

A more time-consuming method that can be used is to adjust the individual weighting for each performance indicator within each holon. For example, if one process had three PIs associated with it of which one clearly related to the performance aspect in question, another had some bearing and the third none, the weighting of the first could be raised (in relation to the perceived importance compared to the second), the second kept in line with its relative relationship to the first, and the third, having no bearing on the performance of this aspect, would be set to zero.

7.7 Implementation: Software Tools

During the initial three-year period of research the CMAM research team developed a windows-based software tool for implementing the above concepts. This was originally named “CMAM”, however, when the author and John Davis began to apply the work at the Highways Agency and the author began marketing the ideas to other clients through FaberMaunsell, it became clear that a new name was required. The software is now known as Perimeta to reflect the idea that it helps the user to get around (peri) and above (meta) the problem (from Greek); and to suggest the link to Performance Improvement.

There are a number of differences between the CMAM tool and the current Perimeta tool. but they are mostly related to user functions, with the overall concepts staying the same. As has already been mentioned in Section 7.6 there is currently further research taking place into the best method for propagating figures of merit up through the hierarchy. Thus, an

additional functionality of selecting the preferred propagation algorithm is being added to the latest version. Nonetheless, the basic functionality and software configuration is expected to remain the same for some time. The author, through her work in industry, following on from her original research, has a number of suggestions regarding “tweaks” that could improve the software and these are detailed in Chapter 10. However, the basic features, described below, would still provide the basic framework. Software is constantly being revised and improved, but the five key elements, described in the following sub-sections, deliver the CMAM methodology presented in Section 7.6. These are (Hall *et al*, 2002a):

1. A graphical tool for drawing hierarchical models;
2. A model manager, to navigate large models;
3. A database of performance indicators, which is intended to be compatible with an organisation’s database and intranet systems;
4. A library of parameterised value functions, which can be chosen and adapted by the user; and
5. An inference engine for implementing IPT.

A sixth element, a graphing tool for illustrating how performance indicators have varied over time, has yet to be implemented. A seventh element, introduced during the move from CMAM to Perimeta is a reporting tool. While this is not fundamental to delivering the methodology described above, it does play a key role in generating higher level “buy-in” within an organisation, by enabling the project team to demonstrate progress in a tangible manner. These key elements are brought together graphically in Figure 7.14 and discussed in turn in the following sub-sections.

7.7.1 *Graphical drawing tool*

This section describes the modelling part of the CMAM and Perimeta software. The first task that it enables is the construction of a process model. Initially the figures of merit for each holon are blank, but as PIs are associated locally and evidence propagates up through the hierarchy more colour appears (Figure 7.7). Each process model is constructed in the process model view window. A new holon is selected by clicking on an icon in the tool bar (Figure 7.8).

The holon can then be dragged and dropped into the desired location. This is facilitated by a grid background to the model view window. The original version of CMAM included a function to automatically sort the model into layers, but this led to some processes being moved in a way that was not intended. To reduce file size when converting to a jpeg (for

transferring models to other documents, such as Word files) and to provide a clear view, the grid can be turned off as required.

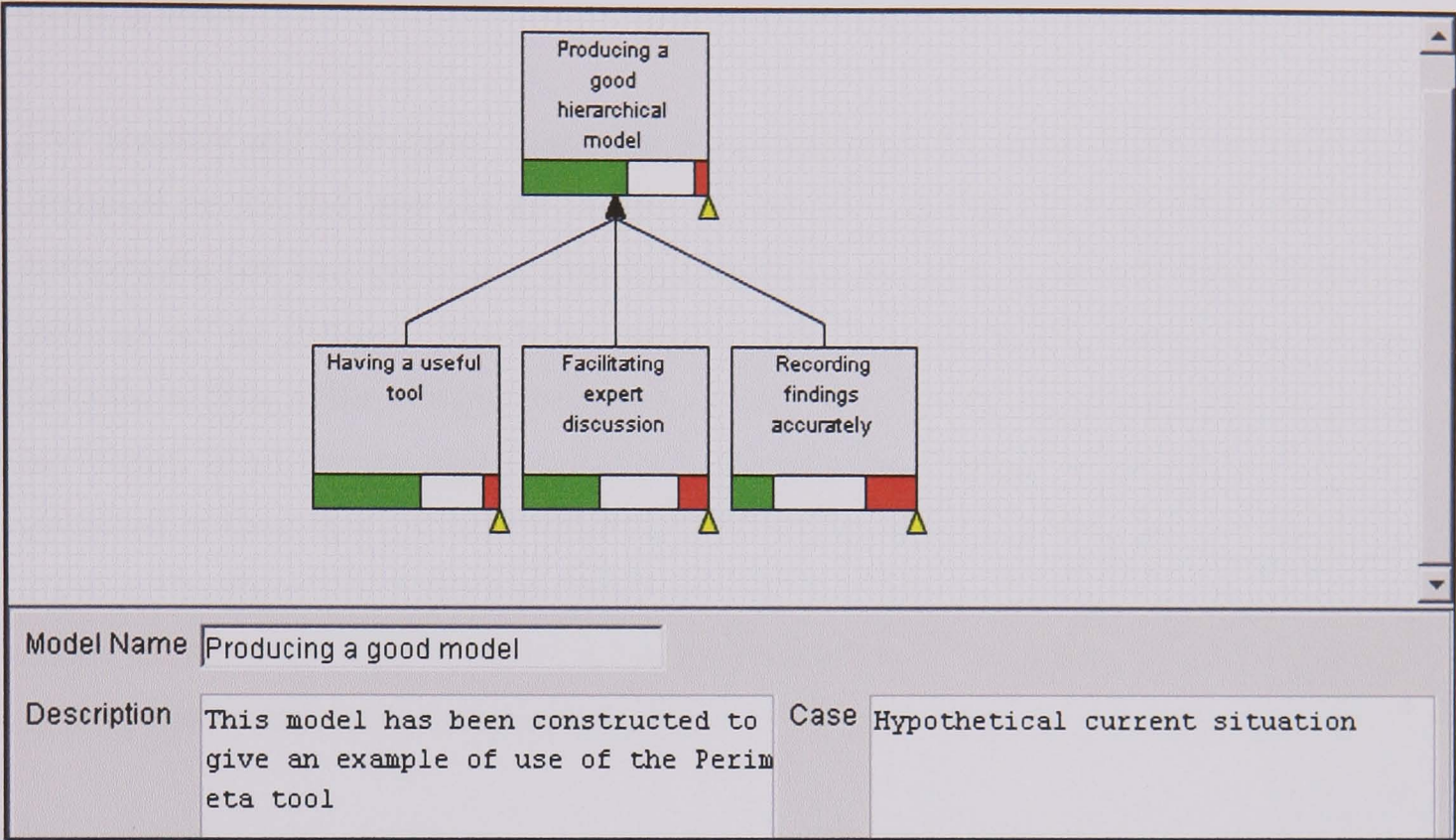


Figure 7.7: Process model window with part of the model information panel

Holons can only be joined at the top or bottom, not the sides. This is to ensure that a hierarchical model is constructed. Thus the drawing tool can display only acyclic structures. Nonetheless, cyclical behaviour (with a time-dependency or input/output relationship between two or more child holons of a parent) can be considered through the use of a convention of time “flowing” from left to right. This is discussed in more detail in the chapters devoted to the case study (Chapters 8, 9 and 10).



Figure 7.8: “New holon” button

The default format of a holon is a grey box for text (the holon name) and a bar underneath which is used for the “Italian Flag” figure of merit. A recent function is to allow the grey text box to be given a different colour, defined by the user. This was introduced following work carried out by the author and John Davis with the Highways Agency when it became clear that it would be helpful to be able to distinguish between holons with certain PIs (say those related to regulation, those with ‘voluntary’ PIs and those with both).

In order to allow the user to distinguish between the “Overview” model and those relating to specific aspects of performance (Section 6.5.5) the background colour of the process model

view can be changed as required. Hence, the safety view might have a pink background, the Environmental performance view a green one, and so on. The “Overview” background colour is white.

The necessity and sufficiency values for the propagation of each child to its parent are displayed on the link and can be toggled on and off. In CMAM and initial version of Perimeta the link was shown as a downward facing arrow, to show that the parent holon “is made up of” the children. The latest versions have an upward facing arrow to indicate the direction of flow of the evidence being propagated. This results in a small black triangle at the bottom of all but the lowest level of holons (the arrow head). The impact of this is discussed in the critique of the modelling tool in Chapter 10. A small yellow triangle is displayed by those holons that have locally entered evidence, to distinguish them from those where the figure of merit is created solely by propagation. This allows the user to rapidly identify holons that are not measured locally.

The calculated values of the interval on the figure of merit can be toggled on as required (i.e. the value of the right of the green and that of the left of the red). However, in practice the author rarely chooses to use this function as it can mislead users into thinking that there is an “answer” value for the performance of any given holon. This is not the case, despite all the handling of uncertainty in the approach the methodology does not give an “answer”, but an indication of how each holon is performing. The approach is an aid to decision-making, not a “black box” solution, which is why hiding the values on the process view is generally appropriate.



Figure 7.9: Holon information panel toggle button

In order to maximise the space in which the model can be displayed, the process model view can be dragged wider by minimising the model manager view (see next subsection). In addition, using the button shown in Figure 7.9 the holon information panel can be toggled on and off. This panel contains key information about the holon currently selected in the process model view. This information can be found under three tabs: “Process”, “Indicators” and “Commentary”.

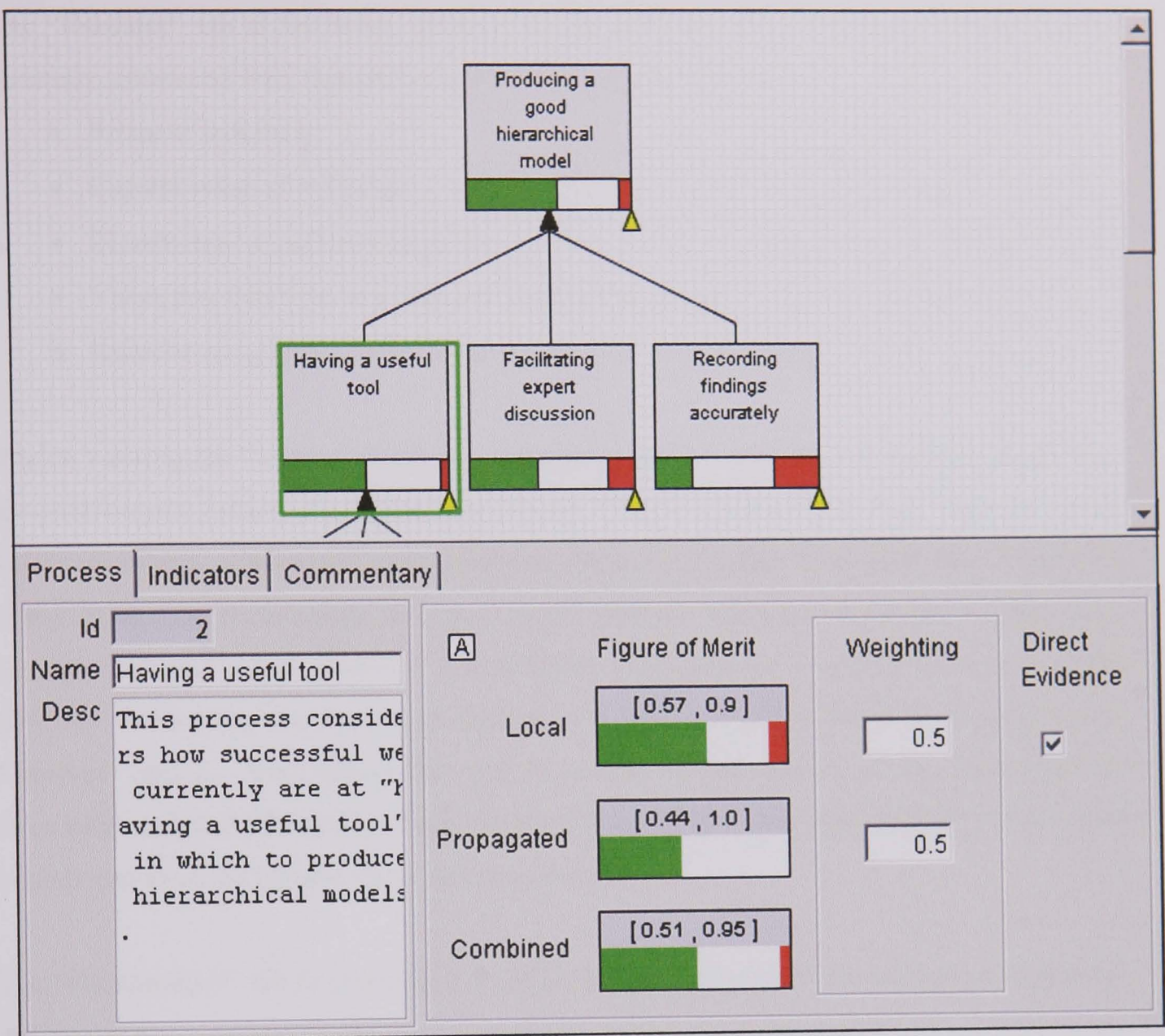


Figure 7.10: Process model with holon information panel showing ("Process" tab)

The "Process" tab in the holon information panel provides space to record and display:

- The process ID (provided automatically on creation of the holon – not editable);
- The process name (see Chapter 10 for more details of process naming);
- A description of the process (currently a free-text space, but could be adapted to include certain fields, such as Process Owner, input, output);
- Three representations of figures of merit:
 - Local;
 - Propagated; and
 - Combined.
- The chosen weighting to be taken between locally-measured evidence and propagated evidence, in order to produce the combined figure of merit; and
- A tick box that allows the user to override the evidence being entered at the local level (the propagated evidence can be overridden by giving it a zero weighting) and entering expert opinion.

The “Indicator” tab in the holon information panel displays key information about the PIs currently associated with that process. This information includes:

- Name of indicator;
- Current value of indicator;
- Dimensions of indicator (e.g. %);
- Value function type (e.g. stepped, concave etc); and
- Relative weighting of that PI (from 0 to 1 in 0.1 increments).

Whilst viewing the “Indicator” tab the user can associate more PIs by selecting them from the performance indicator database (see Section 6.7.3) and associating them with the current holon. Similarly, a “remove” function allows PIs to be unlinked from the holon. Finally, to avoid duplicating performance indicators in the database when the user wishes to map them through different value functions for different processes, or when viewing one of the different views of performance (see discussion in Section 6.6.5) there is an “Amend Value Function” option. This allows the user to change all the aspects of the value function associated with that PI that have been recorded in the PI database, including the performance bounds and even the generic value function shape.

The “Commentary” tab is currently a free-text field. Further uses for this tab are discussed in Chapter 8.

7.7.2 Model Manager Window

The software has conventional zoom functions located on the tool bar, which allow the user to navigate around the process model (see Figure 7.11).

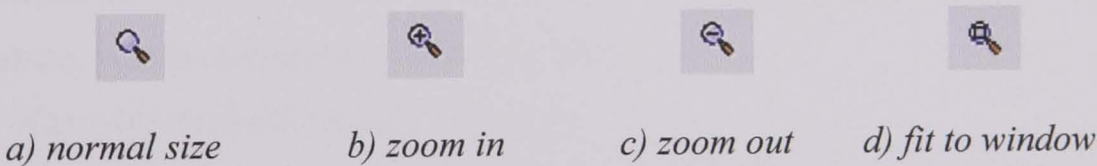


Figure 7.11: Zoom function buttons in the tool bar

However, the nature of a hierarchical model means that it rapidly grows too large for the process names to be clear when the model shown on a single sheet. The model manager is designed to enable the user to move around the model rapidly. In the example below (Figure 7.12) the model manager has been used to select the holon “Having a useful tool” and the structure shown would be displayed in a window to the left of Figure 7.10.

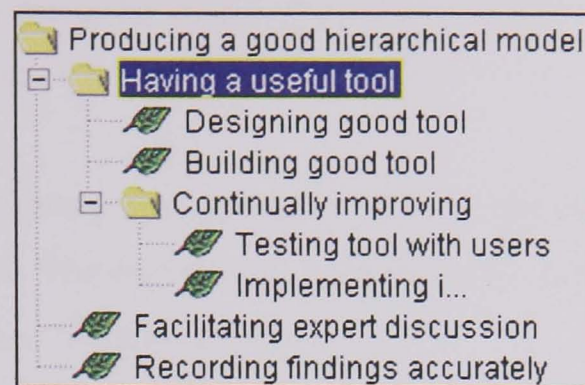


Figure 7.12: Extract from the model manager tool

The model manager looks and feels very much like the explore function that most Windows users are familiar with. Parent holons (yellow files) can be expanded to reveal the children that they have associated to them. Holons with no children are shown with the leaf icon. Clicking on a holon in the model manager moves the relevant holon into view in the process model window. Similarly, as the user moves around the model in the process view, this is tracked in the model manager with the current process always being highlighted. Users can “collapse” child holons back into the parent to simplify the current view in the model manager window.

7.7.3 Performance Indicator Database and Value Function Library

As has been touched on in Section 7.6, the CMAM research team were keen to ensure that the tool allowed all performance indicator information to be stored in one database. This is complemented with a search function that makes finding the relevant PI to associate with each holon very simple. The database is designed using XML to ensure that it is compatible with an organisation’s existing computerised databases (be they off-line or on the Intranet) and to avoid the need for double entry of data. Each performance indicator is displayed in the database, which contains the following fields:

1. Name (of the Performance Indicator);
2. Value (the current value of the PI, plus or minus uncertainty in the measurement);
3. Dimension (for example, a physical measurement, percentage etc.);
4. Value function (name of generic shape used, e.g. stepped, s-shaped, linguistic); and
5. Processes (the names of any and all processes to which the PI is associated).

In the original design (Hall *et al*, 2001) there was to also have been a method providing access to original data, such as time-series, as well as a function to allow simple actions such as summing and averaging to take place within the program. The arithmetic operation and database references were to be entered into a further field. At the time of writing, these two

functions, which are to be called “Combined Value” and “Time Series” are still awaiting implementation (see Chapter 10).

Performance indicators are associated with or detached from holons through the holon information panel. The performance indicator panel has three tabs:

- “Attributes”, which contains:
 - Performance Indicator Name;
 - Performance Indicator ID (sequential, not editable);
 - Description of the PI (free text field); and
 - Value panel for entering current value (either quantitative, plus or minus margin for error or linguistic, with an associated confidence in the assessment).
- “Default value function”, which contains:
 - Value function type (e.g. linear, concave, etc.);
 - Max performance bound (corresponds to performance score = 1);
 - Min performance bound (corresponds to performance score = 0);
 - Curvature (to describe the shape of curved functions);
 - Step/midpoint (for stepped and s-shaped); and
 - Uncertainty (grey area in Figure 7.13).
- “Processes”, which comprises a list of processes to which the PI is attached and a free text field for commentary on the reason for the linkage.

In the original versions of the CMAM software the only options for value function type on the “Default value function” tab were: linear, stepped, concave, convex, s-shaped and linguistic. The z-function was never programmed although it could be useful in cases where the performance indicator is the age of the asset as performance may drop off rapidly at first and then plateau for some years before dropping away dramatically towards the end of the asset life. However, due to the lack of whole-life performance knowledge in the case study domain, this function has not been used to date.

The use of just three parameters to describe curved functions was felt to add simplicity to the tool. However, it resulted in the user being able to set curves where the maximum performance of the system corresponded to less than one, and the minimum to more than zero. In attempt to overcome these issues, two further s-shapes were introduced in later versions of the software:

- S- min/max: Allows the user to set min and max performance values, but not curvature, to ensure that the bounds meet zero and one, respectively; and

- S- min/mid/max: Allows the user to set both boundary values and the mid-point performance.

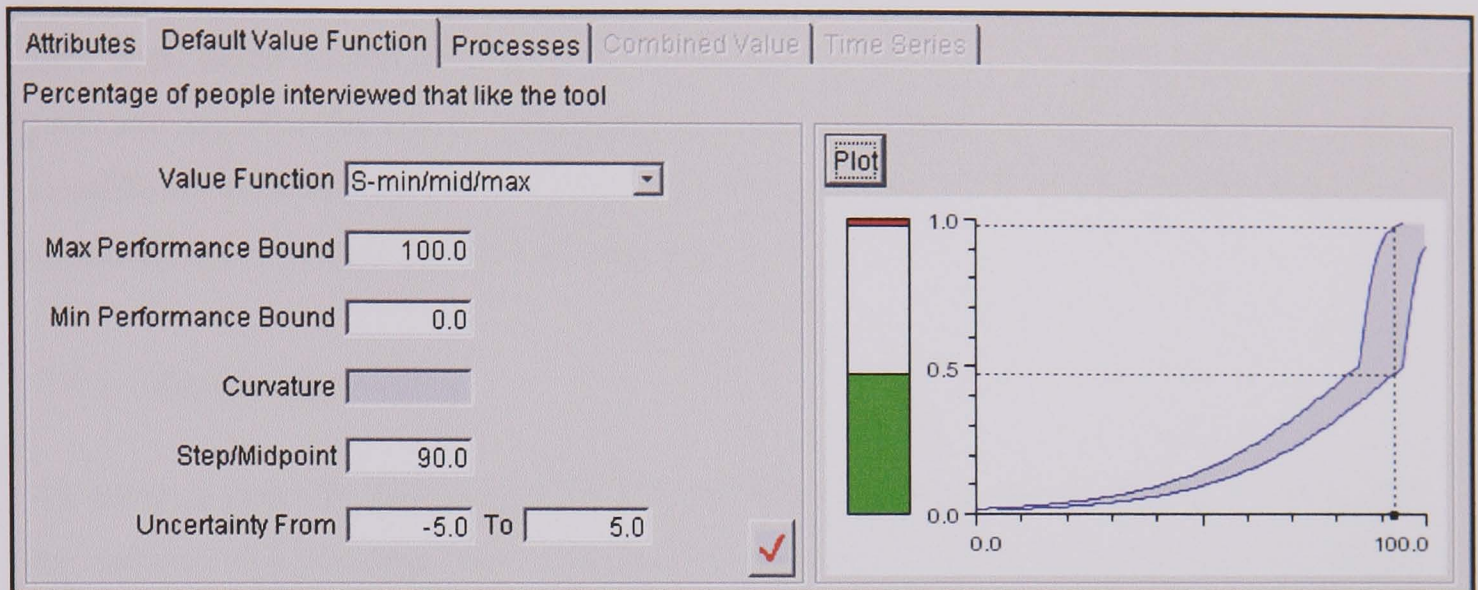


Figure 7.13: Example of an S-min/mid/max function

The S- min/mid/max value function can result in a graph with a sharp discontinuity between the top part of the “S” and the bottom. However, given the uncertainty inherent in the evidence, the expert opinion, and the decision that the system is trying to support, this is more a question of style than a cause for mathematical concern. Nonetheless, a more elegant solution is proposed in the critique of the tool in Chapter 10.

7.7.4 Propagating Evidence through the Inference Engine

Once the child holons have been associated with their parent it is time to change the default values on the propagation. This is done by clicking on the link between each child and its parent. The necessity and sufficiency values on each link can be shown in the process model view, but this level of detail is not generally required. Instead, left clicking on any link brings up the propagation information panel. This contains three tabs:

- “Link” – used in all situations;
- “Pair-wise Dependency” – only used if the user wishes to input dependency between each pair of children, rather than giving an overall value in the “Link” tab; and
- “Conditional Probabilities” – only used if the user wishes to specify the conditional probabilities for each child with regard to the parent (only workable up to two children).

The “Link” tab contains one section entitled “link parameters” which allows the user to set the sufficiency and necessity using a slide bar or by entering a value of up to two decimal places. A second section allows the user to set the dependency value, again using a slide bar

or by entering a value from mutual exclusion between all the child holons, up to complete interdependence. If the user would prefer to enter the dependencies between each pair of children, the “Pair-wise dependency” tab can be activated. This comprises a matrix with each child holon named on both axes. The user can change the dependency between any child and any other by simply altering the number at the relevant cross-section in the matrix. Conditional probabilities are not used for more than two children due to the number of combinations of probability that are required.

7.7.5 Reporting function

An advance from the first version of CMAM through to the current version of Perimeta is the addition of a reporting tool. This enables the user to choose an option from the toolbar that then automatically generates reports in pdf format. One report gives details of all the processes present in the system, including the process name, any description recorded in the software, and a list of all the PIs associated with it. In addition it gives details of the parent of the process and any child holons to which the process is itself a parent.

The second report gives details of all the information in the Performance Indicator database. This is particularly helpful because it puts together the PI name, description and details of the resultant figure of merit as well as displaying the value function with the current information on it. This allows users to print this information out in a format that enables them to take time away from the software and consider the PIs in isolation. The information is delivered as it is stored in the PI database. Any local amendments to the value function shape or performance boundaries, which are carried out through the process information panel, are not included.

Despite this last limitation, the reporting function has proved a real bonus to project teams when working with clients. In particular, generating the report allows those not directly connected with the performance improvement project to understand the volume of work that is being undertaken by their employees. This can be very important for gaining continued support from senior management.

7.7.6 Overview of the tool

The schematic in Figure 7.14 gives an overview of how all the elements of the tool, described in the preceding sections, fits together. Once all the performance indicators have been brought together in the corporate database (bottom left) they are mapped through value

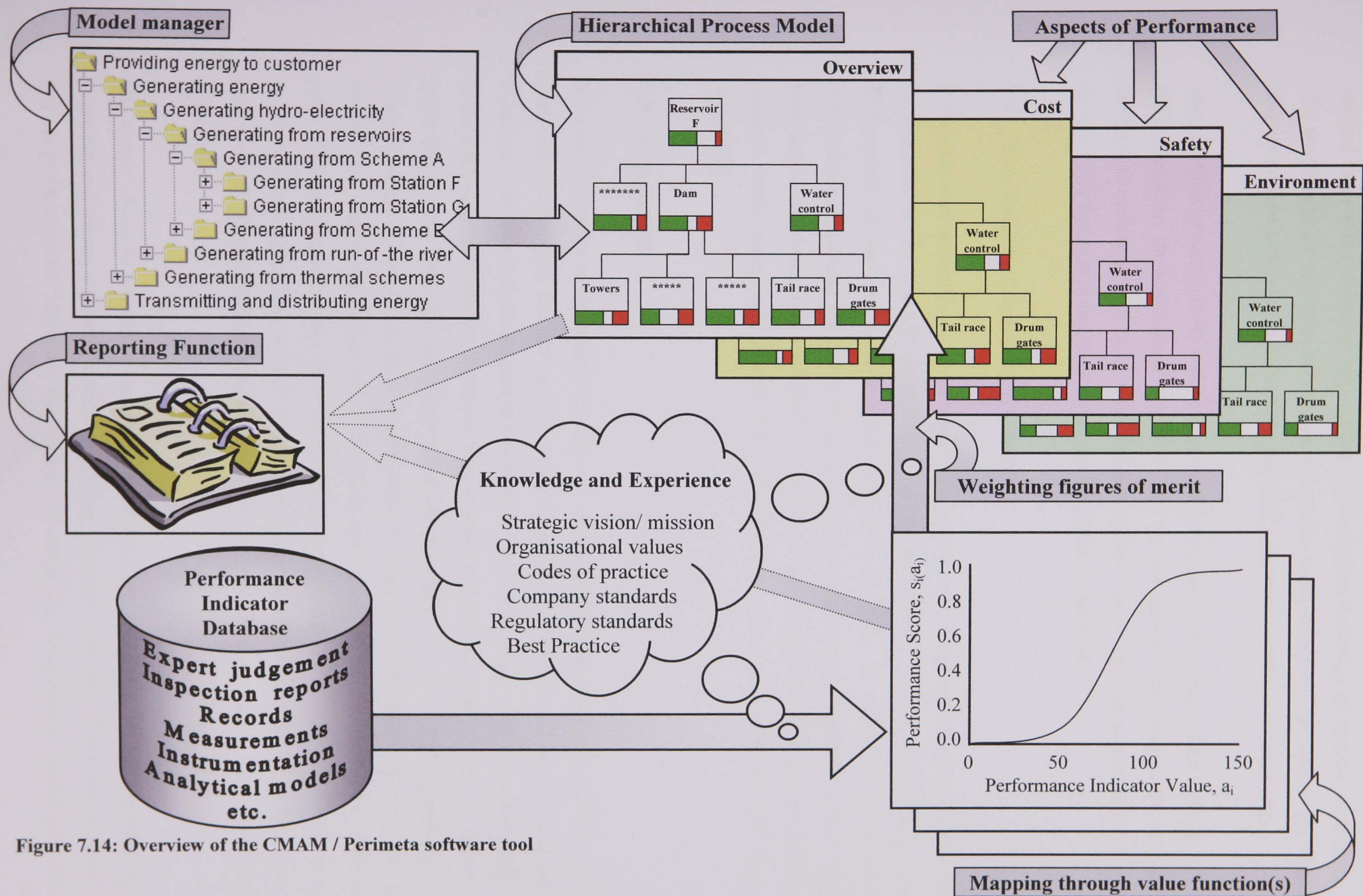


Figure 7.14: Overview of the CMAM / Perimeta software tool

functions (bottom right) according to expert opinion. The resulting figures of merit are then mapped to as many holons as appropriate, and weighted according to relative importance. The weightings on the links and the various performance indicators (as well as the value function) can be changed for each of any desirable aspects of performance (top right).

The resulting process model can be more easily navigated using the model manager (top left). Details of the processes in the model and the performance indicators in the database (along with their respective basic value function details) can be reported in pdf files by using the reporting function in the latest version of the Perimeta software.

7.8 The Need for Modelling Guidelines

It was felt from very early on in the research process that one of the key criticisms that could be launched at the CMAM methodology would be that the overall “result” (e.g. the performance of the top ‘holon’) would depend on the way in which the model was constructed. Therefore, the author began to investigate the concept of generic holons, and rules for constructing process models. The results of this investigation form the core of this research thesis, along with a case study to demonstrate the extent to which they were successful.

7.9 Conclusion

This use of experts to determine the required value function and the weightings for each performance indicator as well as the balance between locally entered and propagated evidence, is an area that allows uncertainty to enter the system. This opens the methodology to the criticism that it may be somehow ‘unscientific’ or not sufficiently robust. In practice, while this is a fair comment, the reality is that the uncertainty is present in the system, since what is being considered is an open world system, not some closed boundary situation where assumptions can be minimised and all factors tested. However, this methodology offers a great advance on previous practice. While it cannot eliminate the uncertainty inherent in a decision, it can make the existence of that uncertainty clear and transparent. In this way, resources can be appropriately directed to attempt to reduce this uncertainty, as appropriate, in the future.

The author chose to attempt to increase decision-makers confidence in the approach by preparing and testing a generic process modelling approach. The aim of this was to ensure that the process model “skeleton” was robust and defensible, thus adding credibility to the

propagation of the figures of merit. The author realised that clues on the path towards a generic methodology would be found in the field of systems thinking. She has chosen to take the term “systems thinking” in a very broad sense, drawing on best practice from a number of sectors, including manufacturing, management, computer science and engineering. An overview of the thinking in each of the best practice in asset management has been given in Chapter 5. Chapter 6 has provided a background to existing systems thinking models, which has been a catalyst for the modelling methodology detailed in Chapter 8. Chapter 9 contains a “fully-dressed” case study, which is reviewed and critiqued in Chapter 10.

Proposed Enhanced Asset Management Methodology

8.1 Introduction

While, as Chapter 6 demonstrates, there is a great volume of knowledge, research and literature related to systems thinking, there is still no rational framework for unifying the existing concepts and providing a cohesive, reliable process for constructing a process model and populating it with evidence for any given asset. Existing models fall into four categories:

- broad diagrammatic models ideas (such as Beer's VSM), which quickly become unmanageable for any model of a reasonable scale;
- detailed methodologies (e.g. Rummler and Brache) that may not be appropriate for every organisation;
- loose and "mysterious" approaches provided by "experts" (e.g. the Value Method; Six Sigma); and
- groupings of detailed models (e.g. the UML, IDEF or Senge's systems archetypes).

As has been demonstrated in the previous chapter, the existing methodologies are either too vague to be applied without the help of expensive consultants, or too prescriptive to add value in every situation. Similarly, the models are either too "fuzzy" to be capture reality, or too complex to be manageable over any significant number of processes.

The methodology described in this chapter aims to address these problems by providing sufficient guidelines to act as a generic methodology, for any sector, with greater transparency than existing approaches such as the Value Method or Six Sigma (see Chapter 6). In addition, the model that is built has the simple appearance of a Qmap model (www.qmap.com), with the advantage of an understanding of uncertainty, and the incorporation of hidden complexity through the use of the Perimeta tool. The suggested approach comprises ten steps, as outlined below. Depending on the dynamics of the group, and the timescales for carrying out the work, the order of the steps can be changed slightly. For example, in some cases it may be

best to complete the work on building the diagram before applying weightings to the various holons (through the links) or attaching any performance indicators (PIs). In other cases an iterative or non-linear approach may be more appropriate, with backward and forward moves and reiterations of steps in a different sequence to that in which they are presented here. The preparation (Step Zero) must occur first, but the very act of preparing for a project may involve the use of some or all of the other steps during a pre-project workshop.

The tables described in Step Five, which enable modellers to check the robustness of the hierarchical model created, are one of the key contributions of this thesis to the field of systems thinking. The model-building “grammar” described in Step Three also facilitate the rapid creation of a robust, defensible and logical model.

8.2 Step Zero: Preparation

Before beginning work with an organisation it is important to identify their current understanding of, and attitude towards Asset Management. This can be done through pre-project meetings, but the most effective method is to hold a short workshop to ensure that the way of working is compatible with the organisational culture

8.3 Step One: Laying the foundations

Although this is the first step of the methodology, it was not developed until towards the end of the period of research. “Laying the foundations” refers to the preparation that is required prior to carrying out a project. In fact, the CMAM team were successful in laying out the goals of the research and did succeed in gaining enthusiastic support from all contributors to the project, not least SSE. Since this methodology was developed as a result of the research, it was not possible to “lay the foundations” from the outset, but it has been included for completeness.

This step involves:

- Establishing organisational buy-in;
- Establishing the high performance team; and
- Organising physical project space.

Due to the innovative way in which this work is undertaken, through the use of workshops and small group sessions, it is not always a familiar approach for many

organisations, particular by those in the more traditional engineering sectors. Therefore it is important to take time to explain the aims, concepts and ideas to those who are participating directly, as well as to other key players in the organisation. In particular, there is often a degree of confusion regarding what is meant by Asset Management, and the fact that it is directly linked to Performance Management.

However, as soon as the term “Performance” is used, there is a tendency for some individuals to become concerned as the word is often associated with personal performance and pay reviews, rather than performance of an asset. This is one reason why the concept of a High Performance Team (Blanchard *et al*, 2002) can be beneficial in raising the status of the project and encouraging enthusiastic and open participation. Providing the correct working environment for the core project team can also assist in ensuring “buy-in” and creating a sense of excitement and enthusiasm to drive the work forward.

The High Performance Team (HPT) should include people from the depth and breadth of an organisation. A core group of players should be supplemented by experts in particular areas of the system when appropriate. As a general rule, in order to cope with the power dynamics in the group (see Step 4), the facilitator should be from outside the system being modelled, be it a different department or, since the model will embrace all departments at the top level (see Step 3), an unrelated organisation. Churchman (Flood, 1999) argues that there is no such thing as a systems expert, however, the ideal modelling team will comprise experts in the system (who are not necessarily used to this type of process-thinking) and an experienced facilitator.

Like Step Zero, this step has been included as a postscript to the original work undertaken with SSE. While trying to extend this work to other sectors and to deliver the ideas as a commercial project it has become clear that many people in all types of organisation are currently suffering from “Initiative Overload”. Even recent developments, still gaining in popularity, such as the EFQM BEM and Six Sigma have proven a disruptive exercise delivering disappointing results. Therefore, some individuals and organisations are extremely sceptical about the idea of introducing another “Performance” or “Quality” initiative.

The author has discovered that an effective way to overcome this scepticism and gain some trust from clients and potential clients is to use the techniques of the Solutions Focus in a sensitive, yet provocative manner. Essentially, the question is asked, “If

you don't need anything to help you improve your organisation's performance, I assume that you are already living in your Perfect Future?". The response will generally be that the current situation is not the Perfect Future, or, that the respondent would not know whether the Perfect Future *had* arrived, because current performance is uncertain. The author then explains that if the current Performance Indicators would not identify the Perfect Future if it were to arrive, then a more appropriate Performance Management Framework, displayed in a simple, visual format, might be helpful. This argument, delivered sensitively, frequently helps to establish the "buy-in" and vision that is essential for the success of this approach.

8.4 Step Two: Scoping Stakeholder Requirements

The work of Churchman, Ackoff and others (Flood, 1999; Capra, 1996) demonstrates that in order for asset management to be successful, it is essential that the whole organisation drives performance in the same direction. Everything must be aligned with the desired outcome, and that in turn is defined by the stakeholder demand.

Successful organisations, be they public or private, interpret stakeholder requirements and express them in their Vision and Mission. This in turn is translated into plans, which deliver the required results within the boundaries of practicality and limitations such as resource, time, and the laws of man and nature. Thus, a process of negotiation is required between the "dream" of management and the practicalities of delivery; a process which has varying degrees of success depending on the success or otherwise of the tactical planners to link the strategic and operational levels of the organisation (Langman and Brown, 2003).

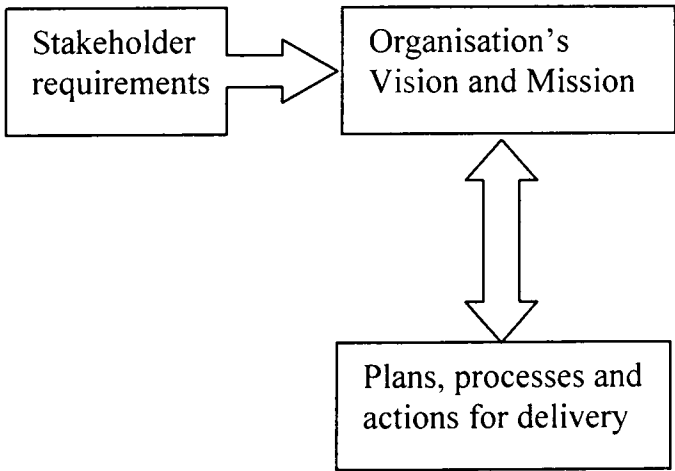


Figure 8.1: Aligning Stakeholder requirements with practical considerations

The UML, thanks to its background in software system design, provides a number of tools for determining the interaction of the customer with the system. In addition, the ideas of Garvin and Kano (Bicheno, 2002), with regard to the definition of quality in the eyes of the end user, should be considered.

It is proposed that the following UML diagrams are used to inform the understanding of stakeholder interactions with, and requirements of, the organisation:

- Use case model (to identify stakeholder interactions with the system);
- Domain model (to begin exploring the links between sub-systems);
- Activity/Sequence diagram (to investigate temporal links).

The UML models can be constructed using a CASE (Computer Aided Software Engineering) tool; or it can be put together on paper. The material used is not as important as the ideas that are captured and the ideas that are promoted by the use of the UML models. The equivalent IDEF models can be used if preferred.

While the demands that are placed on the systems, from shareholders, regulators, neighbours and other key stakeholders are not explicitly illustrated in the final model, they must be understood in order to ensure that the model is meaningful. In other words, because the model demonstrates the current (and, if desired, future) performance of the system, this performance must be relative to some goal. It is meaningless to attempt to assess performance in the abstract, when in fact it must be performance in relationship to some desired outcome. Instead of asking, “How are we performing?” the question must be “How are we performing in relation to our stakeholder demands?”. Thus, the first stage in the generic modelling methodology developed for this thesis has been to identify the external and internal demands being placed on the system. For example, the business practices, interactions between the various actors (members of staff, departments, etc.) within the company, and between the company and its customers, shareholders and other stakeholders, may all be part of the wider system.

While the UML (or IDEF) models are useful for capturing stakeholder views, care must be taken not to allow them to reinforce silo-thinking. Activity swimlanes and sequence diagram “fences” are useful for considering the flow of information and demand through the organisation, and are therefore more suitable for developing a knowledge management model than a performance-focused process model.

Therefore, a clear methodology has been established by the author to ensure that the trap of “silo” thinking is avoided during Step Three.

8.5 Step Three: Building the Process Model

The process model should be built through drawing on a number of different prompts and ideas. The key principles are as follows:

- Be open and creative in stimulating ideas;
- Be strict and consistent in building the process model;
- Keep the detail, but hide the complexity.

The reason for the author stating these principles is that without a formal, strong, process-building methodology the model that is built will be open to criticism, will not be considered robust, and the confusion and debate that will abound could cause the whole project to fail through “analysis paralysis” and doubt. On the other hand, following too closed a methodology (and, in particular, attempting to follow strict timescales, such as those proposed by Rummler and Brache (1995)) can stifle creativity and result in the production of a theoretical model, created almost mechanically, that does not capture the reality of the organisation.

8.5.1 Creative thinking

This methodology is a real advance on the existing approaches described in previous chapters, since it balances the use of creative thinking tools with a structured approach to process modelling. As Figure 8.2 demonstrates, this is a circular process, and it is possible to start with the structured approach first and support it with creative thinking to ensure that modelling does not stall. Similarly, a project team can begin by generating ideas in an unstructured manner and then incorporating them into the process model subsequently.

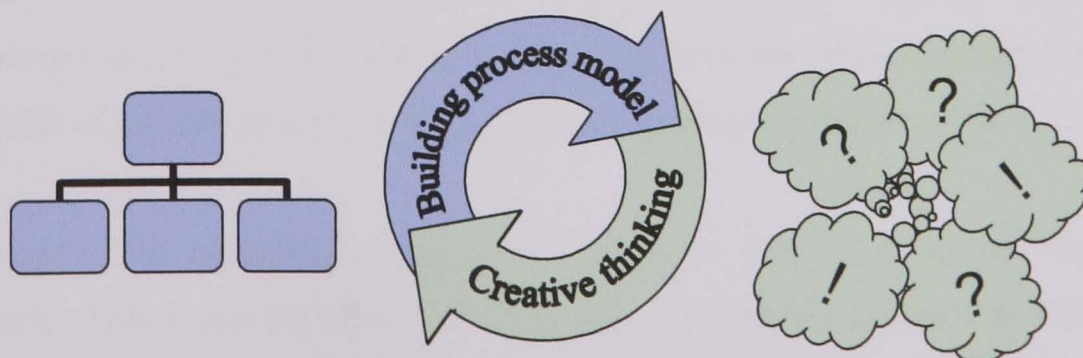


Figure 8.2: The Creativity / Structure Process Modelling Loop

During the creative part of the process modelling, the group should use whatever tools allow them to continue to produce ideas. It is the facilitator's task to ensure that the discussion does not disappear down avenues of detail too early on, and yet at the same time to ensure that the scope does not become overwhelming. With regard to the author's criticism of selecting a problem domain at the start of the project (see Chapter 3 discussion on Kaplan and Norton), the facilitator should encourage a "T"-shaped model from the outset. This will then help to ensure that any localised improvements implemented through the Asset Management plan will actually drive improved service delivery in line with the mission and vision of the organisation.

The facilitator should also try to maintain a "Solutions Focus" (Jackson and McKergow, 2002) ethos throughout the work. The aim should be to model a success scenario; sometimes known as the "happy path" scenario or the "Basic Flow". This is defined as "the typical success path that satisfies the interests of the stakeholders" (Larman, 2002). When referring to the "happy path" or "success scenario", what is meant is the simplified "as is" (Rummler and Brache, 1995) scenario. That is to say, that although the scenario is not perfectly successful (because the performance indicators will not be indicating perfect performance), it avoids unhelpful complexity. It is legitimate to include "unhappy" processes, such as "managing customer complaints", but should not include processes such as "disciplining staff". The former is an accepted business process that will be required from time to time when service delivery occasionally fails to meet the required standard. This is to be expected in an open system dealing with "wicked" (Conklin and Weil, 1999) problems. However, processes such as "disciplining staff" are effectively "parasite" processes, which only exist on the back of poor performance of another process. Thus, such a "parasite" process would only be invoked when the process model demonstrates poor performance in a particular area. Over time some accepted "unhappy" processes may become viewed as "parasitic" processes as the general performance standards, ethos, and levels of expectation rise. Tools such as Goldratt's "Reality Tree" and "Evaporating Cloud" (Goldratt, 1990) may be used once the original model has been built in order to identify those "unhappy" processes, which can be removed.

At this stage of the modelling process the focus is not on how things *fail* but how things *work*. This is not the time to employ risk assessment tools such as FMECA, ETA, FTA; these should be reserved until later in the process (it may be appropriate to employ them in steps 4, 7 and 10). More appropriate "positive" tools that can be used at this stage are (Bicheno, 2002):

- Service Mapping Tools;
- Cycle of Service;
- Moments of Truth;
- Service Blueprinting;
- Creative Thinking Techniques (DePorter, 1992)
- Brainstorming;
- Mindmapping; and
- Solutions Focus (Jacskon and McKergow, 2002)

The Asset Value “flower” (BSI, 2002: see Chapter 5) and acronym methodologies, such as BCIOD+R (Blockley and Godfrey, 2000) can be used to stimulate thinking and ensure a more complete model by ensuring that a number of viewpoints are considered.

Existing documents, such as process charts, the Mission and Vision statements, ten-year plans and so on can provide useful information at this stage. In particular, it is often appropriate to adopt some of the “corporate vocabulary” contained within these documents in order to make the process model seem familiar and “comfortable” to those involved in the project and the senior management who are needed to “buy-in”. However, care should be taken as written process charts may not always represent the “real” processes being undertaken in the system. The only way to ensure that extraneous (“false”) processes are not included, and that “hidden” processes, that nobody notices (often because they function smoothly), are not overlooked, is to follow a robust modelling methodology, as described below.

8.5.2 Robust Structure

In the 1990s, catchphrases like “business process reengineering” and “downsizing” abounded (Dervitsiotis, 1998). These caused fear to many (Walton, 1989; Deming, 1986; Latzko *et al*, 1995; Aguayo, 1990) and resulted in reduced efficiency and effectiveness in the long-term. Therefore, it is important to understand that process modelling, as the term is used in this context, is a method for visualising existing processes so that they can be improved (or supplemented with new processes as required). This is not intrinsically linked to a change in the organisational structure. Indeed, in an organisation like SSE, where the recent merger has resulted in great changes, the process model could, in fact, act as a stable anchor.

The process model structure is dictated using a combination of ideas from two model types:

- Traditional hierarchies; and
- FAST diagrams from the Value Method.

Living systems are not naturally hierarchical, but are in fact adaptive systems in the form of networks (Capra, 1996), and this is also the case for most organisations. Even if the structure is the conventional “silo” style described by Rummler and Brache (1995), the function will tend to be a network, with a few people interacting with friends and acquaintances in other departments, even if no formal communication is in place. However, while modelling such a network might be useful for a Knowledge Management project, it is too complex to form the basis of the kind of model needed to drive an Asset Management plan for performance improvement. Therefore a useful modelling technique at this stage in the process is to place the overall goal at the centre of the network, which then allows it to become the top of the hierarchy, which is in itself defined through six points (Blockley and Godfrey, 2000):

- (i) A system is a hierarchy of process holons;
- (ii) At the top there is only one process holon;
- (iii) Each process holon consists of sub-process holons and sub-sub-process holons according to the level of precision of definition;
- (iv) A layer of holons is at a similar level of precision and definition. The holons interact at the same level to form a description of the whole system at that level. The transformations in each process holon produce the change. A process model of these transformations, available usually only for hard systems, can be used to simulate change. The success of the holons at any level should as far as possible be necessary and sufficient condition for the success of the holons above;
- (v) The layers above are more general, have greater scope and are less precisely defined; and
- (vi) The layers below are more specific, have less scope and are more precisely defined.

It follows from the description above that the higher levels of the system represent the more abstract descriptions. As will be shown in subsequent chapters, it proves useful to name the top holon in the hierarchy in such a way that it describes the mission or vision of the organisation (or part of the organisation) in question. This holon is then “decomposed” through subsequent layers until reaching the required level of detail.

In order to provide a rigorous approach to the process modelling, the “How?” and “Why?” concepts of the FAST (see Chapter 6) diagram are adapted. The major differences between a model produced through this methodology and a FAST diagram are:

- “How?” drives down, instead of from left to right;
- “Why?” acts upwards, instead of from right to left;
- Hierarchical principles apply, e.g.:
 - Child holons of one parent “sum to equal” that parent;
 - No parent has only one child (or it would be the same as the parent); and
 - There are no horizontal (vertical in FAST) linkages.
- The strict temporal placing of FAST does not apply:
 - since, this is not a work flow analysis; however;
 - time generally flows from left-to-right (where appropriate); and
- The “grammar” of the holons is different.

With regard to this last point it is important to note that the wording used when constructing the model is critical to the robust production of the model. This is one of the key contributions of this work.

Simple questions can help to ensure that the wording used is consistent. These are:

- “How good are we/they at.....?”; and/or
- “How good am I at.....?”

The FAST methodology (Kardos, 1988) prescribes a verb-noun combination where the verb is “an action verb” (e.g. hold, protect, rotate, move, control, direct) rather than “passive or indirect” (e.g. provide, supply, become) in order to model the physical effects taking place within the system. The noun should be something that can be measured (e.g. heat, circuit, repair, voltage, volume). Thus an acceptable verb-noun combination in a FAST diagram might be, “direct heat” or “reduce pressure”.

Through the course of this research it has become clear that a different type of “grammar” is more appropriate for a performance-based process model of this type. The author recommends a verb-noun combination, but suggests that the active transitive verb should be expressed in the form of a present participle (i.e. it must have a subject and an object and end in “ing”). This relates back to the discussion, earlier in this chapter regarding the fact that the model is attempting to demonstrate

performance in relation to some goal. While passive forms of verbs can be useful (see Godfrey and Blockley's (2000) diagram, centring on the process of "being a chair, handcrafted for comfort") the author believes that they can allow focus to drift from the overall goal. It is also difficult to imagine how a chair would "consider customers", "do good business" or deliver itself. A more helpful process might be "Selling hand-crafted, comfortable chairs" with a recognition that this entails "getting into the shoes" of the various stakeholders involved.

Although the transitive verb is used, the subject can be omitted as it will remain consistent throughout (i.e., "we", "they", "you" or "I). For example, a useful holon might be "delivering electricity to customers". The "Italian Flag" on the holon will be answering the question "*How good are we at delivering electricity to customers?*". The child holons will explain *how* we deliver electricity to customers. Interrogating any child as to *why* it exists would result in the answer, "so that we can deliver electricity to customers".

The above discussion might appear somewhat pedantic, but a key principle of the modelling methodology is that the diagram should show the system in terms of processes, rather than along the lines of the organisational structure. In early attempts to do this in practice, the author and others within the CMAM research team fell into the habit of decomposing the model along demarcations of elements or geography, rather than a true process view. For example in Hall *et al* (2000) a holon described as "dam" was decomposed into "intake screens", "embankment", "towers" and "anchors". At the time it was felt that this use of physical objects to represent a process view was legitimate as it avoided the need for wordy descriptions in the text part of the holon. The term "POPE" or Performance-Orientated Physical Entity was used for a while among the project team, but having so many words (POPE, process, holon, node) for each holon became confusing and the term was informally dropped. Failure to describe the system in terms of processes will result in the performance improvement opportunity being lost because the link between asset management and service delivery will no longer be clearly defined. Therefore, having the discipline to stick to a strict naming specification is important.

In addition to a consistent "grammar", the author has developed a further tool in order to check the robustness and defensibility of each diagram. This is described in Step Five ("Checking the Model"), however, the method can be used earlier if the modelling team choose to check their assumptions while building the model.

Although the Perimeta software does allow child holons to have more than one parent, (Chapter 7) the author recommends avoiding this wherever possible because it can cause confusion, and also fails to encourage those building the model to question to an appropriate level of detail. For example, one process, such as “maintaining the gate” may actually be masking two quite separate processes, depending on what the overall goal is; such as “ensuring water tightness” and “ensuring mobility of gate”.

8.5.3 *Hidden Complexity; Elegant Simplicity*

One of the main criticisms of the existing modelling techniques described in Chapter 6 is that the variety of symbols can be confusing. For example, the Ishikawa Process Mapping tools offer different symbols for different processes, while the IDEF and the UML have different symbols for each model type (which may be combined in “hybrid” diagrams (Larman, 2002) adding further complexity). The links between holons can also be expressed in several ways. Although the UML only requires the user to provide as much embellishment as absolutely necessary, the advantage of using the Perimeta/CMAM methodology is that each holon is identical in shape and structure to the next, and all the arrows are the same. Therefore, the diagrams that are produced are simple to comprehend because the only complexity is caused by scale.

At the same time, the various tabs within the software enable the detail to be captured. The current software does not prompt the user to enter any more information than the process name. While this is useful for rapid model-building, it does mean that the user must rely on their own will-power and attention to detail to ensure that the appropriate information is entered. The author recommends entering detail in stages to prevent it becoming such a burden as to stifle the creative process and lead to the model-building stalling. However, while the information relating to the links can be added during Step Four (Process Weighting) and details regarding the choice of weighting for each PI can be added in Step Eight (Adding Colour), the following information should be provided in the “Description” box of the “Process” tab for each holon:

- Description of Process (including aim/goal);
- Process Owner;
- Inputs;
- Outputs;
- Resources;
- Source of information;
- Names of people who have entered/modified this information; and

- Date on which information was entered/modified.

The idea of entering the inputs, outputs and resources is supported by the Extended Business Models (of the UML) and results from the general descriptions of process given in standards such as ISO 9001:2000. Capturing the user name and a time stamp should provide traceability to the record and ensure that it is defensible and can be improved through time, providing an information bank of the best practice thinking at the time that the model was built. CASE tools such as Enterprise Architect (for the UML) prompt the user to enter their name and automatically record the date and time of changes. This provides extra Quality Assurance that might be appropriate in future versions of the Bristol tool. The Perimeta tool is written using XML, which should facilitate interaction with other software through the emerging XMI (XML interfaces; Gulbransen, 2000).

Additional relevant information should also be entered for each holon, as appropriate. For example, where the process name or description is found in organisational literature (or is provided by a person or group of people), the source should be recorded. Any discrepancy between the descriptions from various solutions, and the argument behind adopting a particular version, should also be stored for future reference and organisational learning.

It is important to distinguish between the detail relating to each *holon*, as described above and the information, which justifies the shape of the *model* being built. This is captured in the tables created by the author (Step Five). Some methodologies (see Chapter 4: for example: Beer; Kaplan and Norton; Rummler and Bache) prescribe a the number of people that should be in each workshop, and the number of sessions that take place. The author prefers to leave this to the judgment of the HPT and feels that the number of sessions should be set through discussion between the client and the facilitator and should be reviewed on a regular basis. The work must also be carried out in such a way that it can be accommodated into the participants' workload without applying unacceptable levels of stress.

8.6 Step Four: Adding the Weightings

One of the main strengths of the CMAM/Perimeta methodology is that by applying weightings to the various holons it is possible to investigate the extent to which each one contributes to the overall performance of the system; represented by the "top

box”. As has been noted in Chapter 7, there remains some debate regarding the most appropriate method for calculating the propagation of the evidence. The outcomes of these discussions are likely to provide several interesting papers in the months and years to come. However, whatever method is used, a methodology is required for eliciting the information from the project team experts.

This part of the methodology is very much concerned with understanding some of the psychology of human beings. The facilitator must be aware of the power dynamics within the group (Fullan, 2001) and use appropriate techniques to ensure that the most powerful group members do not dominate the outcome. The decision regarding the appropriate weightings must be made by domain “experts” (where “expert” is used in the widest sense; e.g. the general public may be “experts” on areas that affect them, even if they do not have an academic or professional background in the area of concern).

The weighting applied at this stage is, again, not an “absolute” but reflects the judgement ascertained at any given time, based on existing knowledge and best practice. The rationale behind any weighting should be recorded in the “Commentary” tab of the holon and should include:

- Names of Consultees;
- Date of consultation;
- “Weighting” given to different voices;
- Method used for eliciting information; and
- Any comments/problems by the facilitator.

The weightings can be gained through open discussion or debate within the group. This can reflect the Dialogue of Senge (1990), but dissenting voices should not be ignored. The facilitator may wish to play “Devil’s Advocate” if a consensus is reached very rapidly, or will need to provide a mediation role in some other cases. Sometimes voting can be used to get to an answer rapidly, but care must be taken if there is: a particularly powerful voice; a wide range or more than one peak in the voted value; a bias towards one point of view within the group. These problems can be overcome through the judicious use of anonymous voting and, where one view is under-represented (e.g. five “engineers” and one “ecologist” discussing a bypass), the person or people representing the likely minority view may be given extra “weighting”.

Another benefit of the CMAM approach is that it allows views to be considered in isolation through the use of the aspects. For example, the same diagram can act as a different model through considering particular aspects of performance, such as “safety” or “the Environment”, which is done through viewing the original model in a different window with revised weightings given to “tune out” processes and (once they have been added) performance indicators that do not contribute to the aspect of performance being considered.

Clearly, this step of the approach can raise strong emotions and the facilitator(s) must be able to manage these to capture the creative feeling and provide a meaningful weighting. The techniques of Neuro Linguistic Programming (O’Connor and Seymour, 1990) or the Solutions Focus may be appropriate in this context

8.7 Step Five: Checking the Model

The construction of the model, and the weightings applied to the various links, is clearly not a strict science. In the view of the author it takes into account three key, interrelated elements of human thinking:

- Knowledge;
- Logic; and
- Belief.

The structure of the model is related to the logical process of tracking the “how?s” and “why?s” through the system, while the weightings applied to each process depends greatly on the belief of the project team. Therefore, a logic-based and a belief-based method have been developed for assessing these elements. This step of “checking” the model is actually revisited several times throughout the process, and the use of a High Performance Team (HPT) approach is also self-checking (as the team debate each issue as it arises).

The author recommends that the model should first be checked before any performance indicators are applied. This is useful for several reasons:

1. Provides early feedback;
2. Introduces “reviewers” to enough of the work to interest without overwhelming;

3. Establishes “buy-in” with wider group (who are then more likely to share performance indicator information for subsequent steps and contribute to future reviews); and
4. Gives HPT renewed enthusiasm if review is constructive.

The first element, “Knowledge” is easy to review. The HPT open up the work to interested parties within their organisation, in the stakeholder groups (including regulators and up and down the supply chain). The “Knowledge” can include everything that is captured in the descriptions of the process and checks that details of the process owner, description, inputs, outputs and so on are current, complete and correct.

All the comments gained during this process will be given in the context of the “Belief” of the contributor. It is therefore up to the HPT and the facilitator to agree the extent to which the “Belief” of the reviewer is compatible with their own perception of reality. Again, this is a soft issue, and may be facilitated through considering some of Checkland’s ideas (particularly the rich pictures). Finally, it must be remembered that there is no “right” answer. The whole point of the model is to capture the current Knowledge, Logic and Belief, in order to provide a foundation, which can be improved upon over time. This model provides a “mark in the sand” which can be refined as understanding develops. Without capturing the existing situation it is likely that future generations may, inadvertently, reinvent a “wheel” that has previously been shown to be flawed.

In this context, “Logic” applies to the structure; the “how” and “why” of the model and this can be checked through consultation, but a more rigorous methodology is to follow the “flow” of demand and response throughout the system. The key principle is that the “top box” of the organisation, the mission or vision, essentially translates the demands of the customer or stakeholder and passes them on to the relevant parts of the organisation to be delivered. In practice this is done through the strategic plan. Each division or department will negotiate with the owners of the top box (e.g. the Board) to gain funding and resources for delivering the demand. In turn, processes at the higher levels will pass on the demand in the form of tactical plans (later filtered into operational plans).

This process is shown schematically in Figure 8.3. It is interesting to note that the “Customer” is shown separately from the other stakeholders. This is because he/she is

the reason that the organisation exists in the first place; making a demand that the organisation meets. The Employee has one “foot” in the organisation and one with the other stakeholders. This is to take into account the fact that the organisation could not exist without the Employee, but they may also be one of the other stakeholders when in their normal work role (e.g. Union Representative, Neighbour, Shareholder, or another Customer).

The Employee should have an influence on the Mission and Vision, and therefore on every process in the business (indirectly or directly). The “top box” is a strong colour as it is clear what the Mission and Vision is. This becomes diluted as it is decomposed through the various levels of the organisation. However, at any level, the processes will add up to the same “shade” as their parent, thus each holon is to a greater or lesser extent a “reflection” of the top holon.

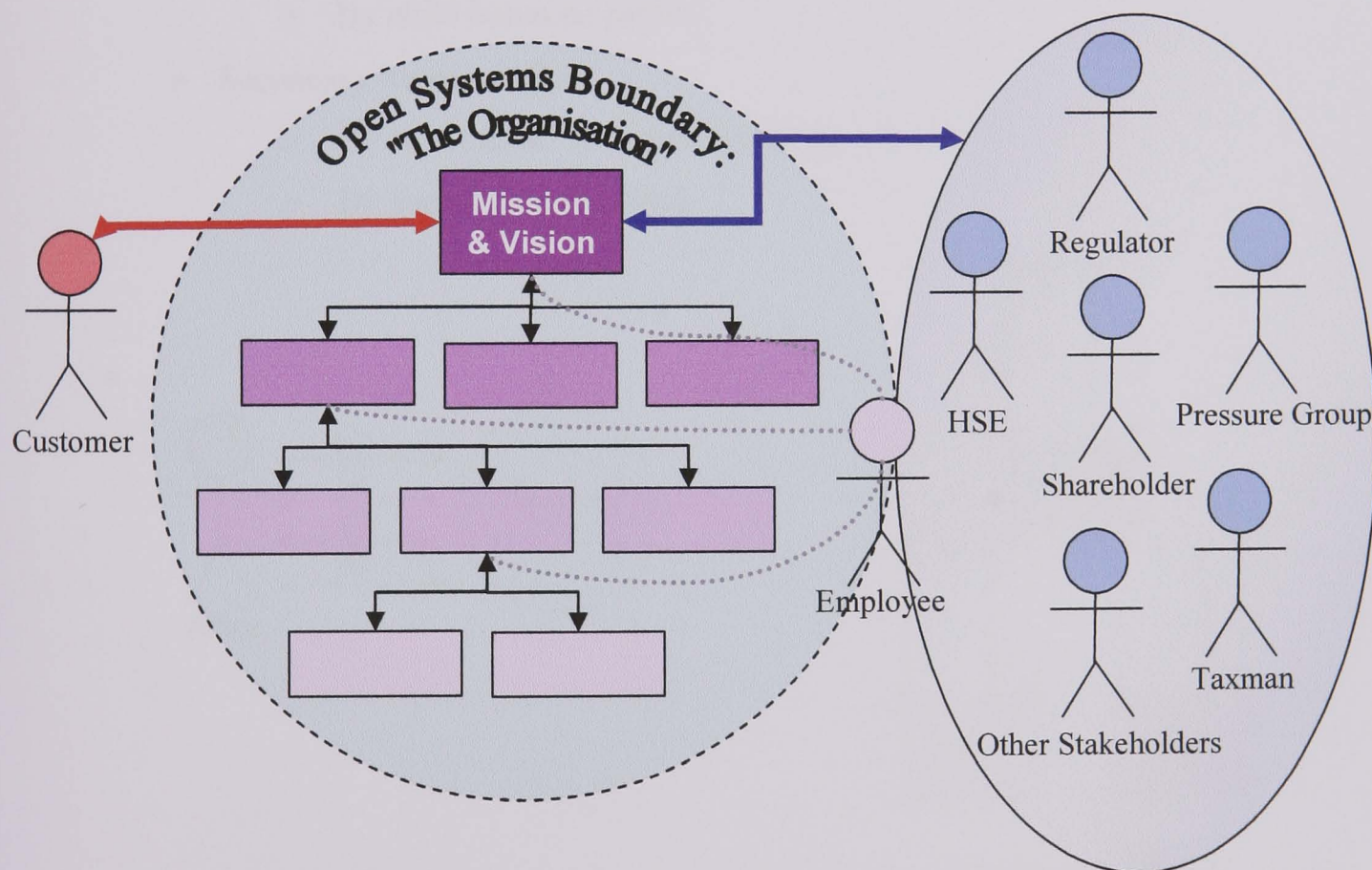


Figure 8.3: Schematic of Demands and Responses Acting on and within the Organisation

All the way through this process, an exchange is being negotiated as follows:

- Organisation receives a demand (or several demands);
- Organisation creates Vision or Mission to meet external demands;
- Vision or Mission is made “top box”;
- Strategic level processes pass demand to child holons through tactical plan;
- Each parent passes on its share of the overall demand (goal) to its children;
- Each child demands payment for delivering its share of meeting the demand;

- Each parent pays its children for delivering; and
- The organisation charges the customer for delivering.

Each arrow shown in the schematic represents four exchanges of information in negation. These signals are shown in Figure 8.4:

- Primary Demand (Dp);
 - By “Customer” on Organisation; or
 - By parent holon on child;
- Primary Response (Rp);
 - By Organisation to “Customer”; or
 - By child holon to parent;
- Secondary Demand (Ds); and
 - By Organisation on “Customer”; or
 - By child holon on parent;
- Secondary Response (Rs);
 - By “Customer” to Organisation; or
 - By parent holon to child.

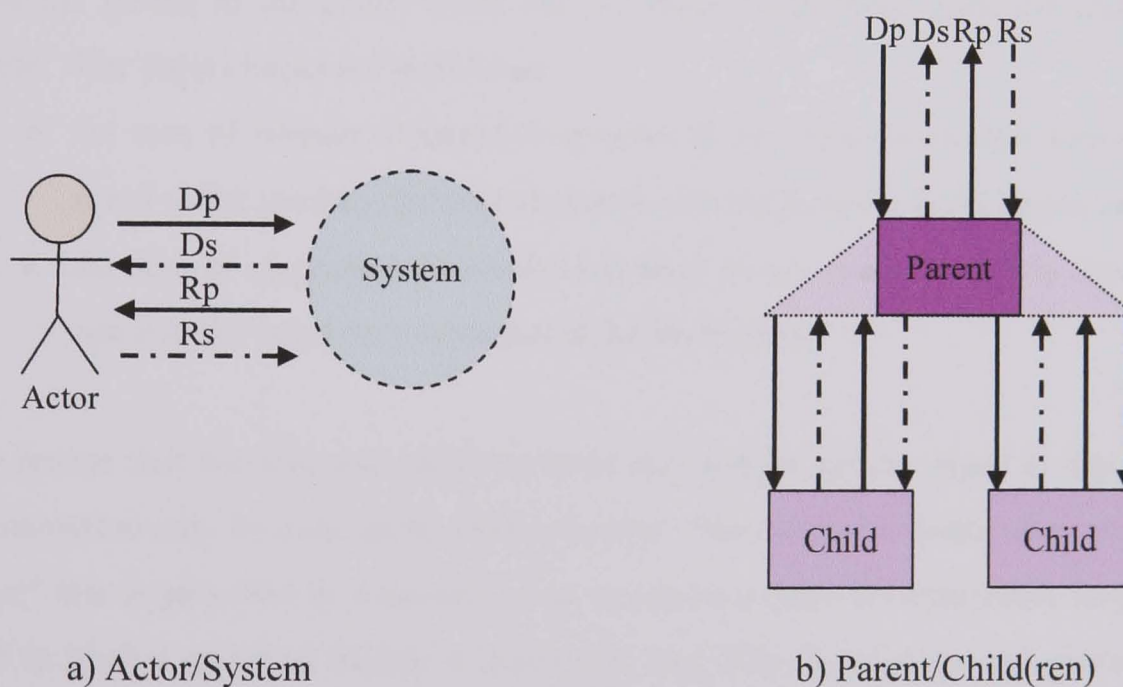


Figure 8.4: Demand and Response relationships

The demands and responses flowing between the system and external customers are considered “external”, even though they affect a change internally. These are considered using the UML/IDEF and are identified during Step Two and can be studied in further detail using the various other diagrams. The internal demands and responses flow between each parent and its various children. These could be shown on a model (extending Figure 8.4) but this would soon result in a violation of the goal

of “hidden complexity; elegant simplicity”. Thus the author has developed template tables to capture this information. The same template can be used for considering both internal and external demands and responses. Following the lead of HAZOP (IEE, 2002a) the author has chosen to use prompts in the form of questions to help the process modellers fully explore the problem domain and produce a rigorous, robust and defensible model. The table template is given in Table 8.1, and an example is shown in the next chapter. Further examples can be found in Appendix C.

The conversation between the child and parent is as follows:

Parent: I want you to meet this demand (Primary Demand, D_p)

Child: You must give me these resources (Secondary Demand, D_s)

Parent: I agree to provide these resources (Contract agreed)

Child: Here is what you asked for (Primary Response, R_p)

Parent: Here is your payment/ resources (Secondary Response, S_p)

Note that the parent may provide resources before the child can deliver the response, or payment may be made after the event. The *primary* demand and response flow from the parent to the child, while the *secondary* ones flow from the child to the parent. The logic checks are as follows:

- the sum of primary demands/responses at any level is *slightly more than or equal to* the primary demand/response coming from the level above; and
- the sum of secondary demands/responses at any level is *slightly less than or equal to* the secondary response at the level above.

The reason that the responses and demands may not be exactly equal is that some of the resources may be used up by either process. This can be considered as the “added value” that is provided by a process. For example, a head of department may require staff in his/her group to deliver a service in line with the mission and vision of that department. However, the head of department will also have negotiated a budget and resources, which he/she will pass onto his/her staff. At the same time, the head of department will consume some of this budget and resources and will also (locally) carry out some work that will support the mission or vision that is to be delivered.

In other words, the process may consume some of the secondary resources before passing them on to the child processes, and may consume some of the primary response before passing it up to its parents. The ideal system is one where primary and secondary response are conserved as much as possible. For example, where the

primary demand is electricity, more energy must be “used” than will eventually reach the customer because some will be lost in heat, friction and so on. Similarly, if the secondary demand of the generation system is money (for maintenance), some of that money will be invested within parent and sibling processes that enable that maintenance to take place, and the amount spent on “red tape” should be brought to a practicable and safe minimum.

Table 8.1: Overview of one Customer/Supplier or Parent/Child Interaction

| Primary actors | Interests |
|--|--|
| <u>“Customer” (or parent holon)</u> | Primary Demand; Secondary Response |
| <i>“Supplier”(or child holon)</i> | Secondary Demand; Primary Response |
| Precondition | What must happen before this process can take place |
| Success guarantee (post condition) | The situation after this process has taken place |
| Shadow usage cases | Related processes: “unhappy” or sibling holons and “parasites”(What happens if the process fails – do not model parasites in main model) |

A creative tool has been developed for stimulating an understanding of the demands and responses. The use of the word “I” encourages the modelling team to view the system from the point of view of the parent and child holons, to see what each wishes to gain from the interaction. An example is given in Table 8.2.

If any of the primary demands cannot be met by the child/supplier, because, for example, the parent does not meet the secondary demand, or because the child holon has failed, then this failure will feed up to the parent process. Depending on the necessity of the child (see Chapter 7) the overall external demands may only be partially met (or the system may fail). In order to view the impact of good or poor performance of holons in the system it is necessary to associate evidence to each holon. Steps 6-8 describe this process.

Table 8.2: Detailed Prompts for the Customer/Supplier (Parent/Child) Interaction

| | Prompts | <u>“Customer”</u> Requirements | <u>“Supplier”</u> Requirements |
|---|--|-----------------------------------|-----------------------------------|
| 1 | What do I need from this transaction? | Primary Demand (Dp) | Secondary Demand (Dp) |
| 2 | How much of it do I want (from this transaction)? | | |
| 3 | When do I want it? | | |
| 4 | Where do I want it? | | |
| 5 | How do I want it (quality)? | | |
| 6 | How much will I give for it (depends on values and perceived level of need)? | Secondary Response (Rs) | Primary Response (Rp) |
| 7 | Why do I need it (why do I value it)? | | |
| 8 | Who will I get it from? (linked to 6) –preferred supplier | | |

8.8 Step Six: Assembling the Evidence

The great advantage of using the CMAM tool is that all types of evidence can be collected together to give an indication of how the system, and individual holons within it, are performing. There are two approaches that can be adopted for collecting evidence. This could be done according to the area of the business (e.g. departmental function) or according to the evidence type. The easiest method will depend on the way in which data is currently stored (or who owns it). For example, it may be that all health and safety related information is stored in one place for all departments, while everything related to a particular asset, regardless of the level of detail, is stored together.

All of this must be carried out in light of the priorities for evidence that will have resulted from previous steps. Therefore, it is important to concentrate on identifying evidence for those processes that are considered key to the performance of the system as a whole. Step Four will have illustrated that there may be some holons that have relatively low sufficiency and necessity and therefore finding evidence for those processes will be of a much lower priority. Through using the process model to prioritise the evidence that is required, the resulting performance indicators will form a

more meaningful “cascade” than can be achieved through other methods (e.g. Bititci and Carrie, 1999).

Generally it is simplest to begin by looking at the reporting functions within the organisation and identify what data they have available. In this way it is possible to begin putting the data and information into some context from the beginning, as it is clear what it is currently being used for. Therefore, a report on the condition of a turbine might be collected at the same time as operational information. To save time the project team can begin the process of applying value functions at the same time as collecting the information; thus minimising the number of times that an expert will need to be disturbed. However, if the HPT have easy access to the expert it is usually better to collect information and data through a series of short, informal sessions, slotted in when the expert is not fully occupied with his or her “real job”. This can add to the “buy-in” and support for the project, described in Step One.

The EFQM Business Excellence Model and the Balanced Scorecard of Kaplan and Norton provide a model for understanding how performance indicators can be created and “balanced”. However, as has been discussed, the methodologies provide something of a “bottom-up” approach and there is not a clear link to process. Having said that, it is important not to alienate anyone within the organisation and it would be foolish to waste any of the investment that may previously have been invested into these systems. Therefore, if one of these “scorecarding” initiatives has taken (or is taking) place in the organisation this is an excellent place to begin the search for performance indicators. However, care should be taken not to become “blinkered” by these approaches when the PIs are attached to the model, as they may feed into more areas of the organisation and more aspects of performance than had originally been envisaged by the “scorecarders”.

The HPT must take the time to set up a comprehensive system for managing the data and information that is available and prioritising the order in which it is passed through a value function and added to the process model. It is not recommended that all PI values be added to the CMAM/Perimeta database immediately as the group may discover that upon trying to add Value Functions to certain types of data, that it becomes clear that what is being presented as a PI actually does not relate to performance but is instead simply a QA measurement. Instead, the researchers can begin by specifically looking for evidence that is likely to apply to the key processes within the model (e.g. those with the highest sufficiency and necessity). This is the

most tiring and least interesting part of the work as it is usually involves individuals hunting for evidence throughout the organisation; something of an anti-climax following the workshops required for the previous stages. It is therefore essential to ensure that those carrying out this work are given appreciation by the group and that the task is not left to just one or two people.

Despite the lack of “glamour” of this task, it can be interesting to discover that the information that is most readily available, and in an accessible format, is often not related to performance at all, but is merely an inventory of assets. Much of the evidence that is most critical for making decisions related to key processes will tend to be in the form of survey reports and other documents. This is why the qualitative value function has proved so useful and is such an advance on other “Asset Management” systems, as described in Chapter 5.

When quantitative PIs are available, the research team should begin investigating the level of certainty associated with the data. Uncertainty can arise from a number of sources, such as:

- Inaccurate data collection techniques;
- Poor recording methods;
- Inaccurate description of recording methods;
- Gaps in data records;
- Corruption of electronic databases;
- Missing titles on tables;
- Unreliable sources (e.g. untrained staff); and
- Age of data and information, etc.

In the short- to medium-term it will probably be necessary to capture all evidence manually and type it into the PI database in CMAM/Perimeta. In the longer-term, once an organisation sees sufficient value in the work, the existing databases could be automatically linked. At that point this step will still remain important, but it will be a question of reviewing the automated data collection processes to ensure that standard procedures are being met and no additional uncertainties or errors are being brought into the data through the automation.

Once again, soft issues are very important and the project team must be careful to ensure that those being asked for data and information do not feel threatened by the

request. Unfortunately, there are historical reasons (Fullan, 2001; Senge 1990) why some individuals feel safer hoarding information. For this reason, part of Step One should involve senior management making clear that efficiencies that result from this work (i.e. from discovering that some data is not required and no longer need be collected) will result in resources being redirected to more important tasks (in terms of the overall performance of the organisation), not in redundancies.

8.9 Step Seven: Applying Value Functions

There are several value functions that can be used to map evidence from performance indicators (or data that indicates performance but has not previously been thought of as a PI) onto a figure of merit (Italian Flag). While the facilitator should help the HPT identify the appropriate shape for the function, it is up to the domain experts to make the final determination. As Figure 8.5 demonstrates the evidence of performance may be captured in many formats including paper sources, databases, and photographs. Once the evidence has been collected together using the approaches described in Step Six, the next step is to begin to interpret what it means in terms of performance.

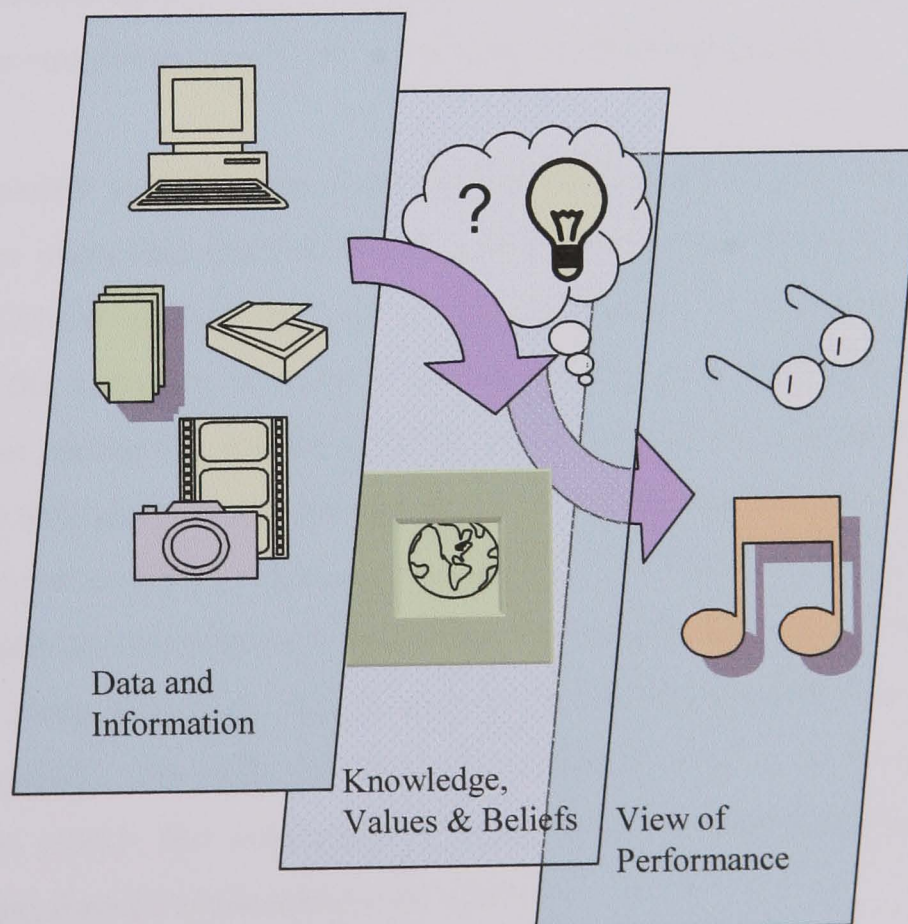


Figure 8.5: Filtering Evidence to gain a View of Performance

The value functions act as a framework for capturing the knowledge, beliefs and values of experts. This is done through looking at their frame of reference and view of

the world. One approach for doing this is to build value functions for performance indicators during workshop sessions. This can be done through projecting the CMAM/Perimeta tool onto a wall, or by drawing it on paper or a white board first. Many participants prefer the latter to begin with, but soon become comfortable with entering the information directly into the software.

The advantage of developing the value functions in a workshop is that it is possible to gain a wider view of what a particular PI value represents in terms of performance. The disadvantage is that it is difficult to keep to an area that is of interest to all participants, and some people may feel frustrated or that their time is being wasted (even if their view would be helpful). Also, the power dynamics of the group can be an issue and it is much more time consuming to gain a view of a value function anonymously than to vote secretly on the value of a weighting (see Step 4).

The author therefore suggests that a second method is generally preferable; developing value functions through one-to-one interviews or small group working. The results can always be verified at a later date through consultation, in the same way that the model was checked during Step 5 (and perhaps to the same group of people, as they should now be comfortable with, and supportive of, the methodology).

As with the earlier steps the aim is not to find the “right” answer, but to provide a framework for improving decision-making, and therefore performance, in the longer term. The CMAM methodology allows for “fuzziness” in the shape of the value function, but this can often be quite difficult to assess. As a general rule it is a good idea to set the uncertainty for the *value function* (but not the performance indicator value) at zero to begin with and then revise this following later rounds of consultation. Although this carries a risk of ignoring uncertainty, it will ensure that the information is captured quickly and relatively painlessly. Otherwise there is a real danger that inertia could creep in and key experts may avoid contributing their views because of the time required. As with the evidence collation step, it is usually far more productive to collect the information through short, informal, chats; rather than through longer, formal “brain-download” sessions.

To maximise the effectiveness of each brief session with an expert a proforma could be used to prompt the interviewer. This should remind them to ask questions such as:

- What is the lowest value you have ever heard of for this PI?;
- What is the largest value you have ever heard of for this PI?;

- What are the specified minimum and maximum values for this PI?;
- Do you agree with these specified limits:
 - Are they meaningful?
 - Are they attainable?
 - Are they practicable?
- At what value is it not worth spending any more to improve performance?;
- What would be a value where performance became just barely acceptable?
- What value would represent fantastic performance?; and
- What value would represent terrible performance?

The interviewee is likely to respond that it depends which process the PI is being used to measure. At this, the interviewer can begin to drill into the relevant processes and make notes for later regarding which PIs are the most likely to give a good indication of the true performance of any given process. Asking directly which processes are measured by a particular PI may result in difficulties because:

- The interviewee may not know why the PI is collected and may become embarrassed or defensive;
- The interviewee may feel under pressure and forget key processes; and
- The interviewee may wander off on a long tangent of anecdotes.

Once initial value functions have been applied to each PI they can be added to the information that is currently stored in the PI database in Perimeta/CMAM.

8.10 Step Eight: Associating Evidence with the Diagram

The evidence, prioritised following Step Four, and interpreted through a value function in Step Eight must now be associated with the process diagram. This is usually best done in a group setting because new linkages are likely to be found as some members of the group find out about data and information that they never knew existed, and find applications to their area of interest. This will frequently result in a new Value Function being needed because the PI will imply a different level of performance depending on which process it is associated with, or, which aspect of performance is being viewed.

One of the current difficulties with the CMAM/Perimeta tool is that there are no “baskets” of performance indicators in the PI directory. While this is sensible in programming terms (allowing the user to quickly search just one vault of information)

it does cause difficulties in noting that one PI has more than one value function associated with it. This can be overcome by the HPT developing a consistent wording protocol for the naming of each PI. By including the same key words in the title, full use can be made of the tool's searching capability.

As the evidence is associated with the diagram, a number of tasks can be carried out. Firstly, where more than one PI is associated with one process, the relevant weighting of the PIs can be adjusted to demonstrate which PIs are considered to be most representative of the performance of the holon. This is best done in a workshop setting (with anonymous weighted voting if the power dynamic requires it).

This is a good time to adjust the dependency of the child holons to take into account any "double counting" that could take place where evidence for two or more child holons is related. This dependency may result from both processes relying on the same evidence, or from some other relationship, such as the same engineer carrying out the visual inspection or a known link between one parameter and another (e.g. temperature and stiffness; age and condition; etc.).

The third task that should be undertaken at this time is to adjust the weighting between "local" and "propagated" evidence for any given holon. In addition, if the group feels that the information with a process is misleading or incomplete, the "direct evidence" function (see Chapter 7) can be used to compensate for this.

All three of the changes described above must be recorded for future reference. It is recommended that the reason for a change in the dependency be recorded in the parent holon of the links concerned (to avoid repeating information for several children). The reasons for the individual PI weightings and local/propagated weight, should be stored in the commentary relating to the holon concerned.

8.11 Step Nine: Understanding and Reviewing

Once the model has been constructed and the evidence associated, a number of findings will become clear. For example, by choosing the "no propagation" option in Perimeta v.1.0 the HPT can quickly see where there are gaps in locally available evidence. There are three key tasks that can be carried out once the evidence begins to be propagated. These are:

- Scenario Testing:

- Benchmarking; and
- Gap Analysis

8.11.1 Scenario Testing

The way in which scenario testing can be done is through a methodical or informal process of moving the amount of red and green in each process to see how this affects the performance of the processes above. The scenarios that can be tested are:

- The effect of uncertainty;
- The effect of reducing evidence of poor performance; and
- The effect of changing weightings.

It is human nature to become preoccupied by areas of the system that are known to be failing. Indeed, the traditional engineering approach to design is to first “identify a problem” and then design a solution for it. In reality though, the greatest problem tends to be that no-one knows what the problem is.

Risk assessments, as used in the dam sector and elsewhere (Chapters 4 and 5) help to identify the extent of the detrimental consequence that could result from failure of an element. The danger is that areas where failures might occur, but have not been thought of, will be overlooked. At the same time, the existence of “good” risk are ignored; that is, that the bad consequences of *not* doing something might be considered, while the good consequences of *doing* something may not be considered as part of the prioritisation of work. This approach aims to overcome both these issues.

By converting “white” into “red” it is possible to see the potential catastrophic effect of failure of a particular process. Where this is the case, monitoring resources should be deployed, while, if reducing the red has little effect on the parent above, it may be possible to argue that monitoring and other intervention might be better spent elsewhere.

Similarly, by converting “white” into “green” it is possible to investigate the benefits of intervention in a particular area. In this way tactical planning can be undertaken and its effects on the strategic goals can be demonstrated.

8.11.2 Benchmarking

One of the original goals of the risk-based approach in the hydro-electric dam sector was to produce a single value for the probability of failure (Pf) of a dam (Hartford, 2000). It was felt that if this could be calculated quantitatively and matched with some reliable estimates of consequences, then it would be possible to benchmark safety in that sector with, for example, the nuclear power industry.

As it turns out, this hope of a fully quantifiable Pf and consequences has not been realised, and is unlikely to be possible in the near future (see discussion in Chapter 4). In addition, if benchmarking is to take place across one sector, let alone more than one, then it is going to be necessary to take into account the fact that the demands and needs are not uniform geographically.

The approach described in this thesis can be used for benchmarking because it allows different value functions to be used for the same performance indicator. Thus, while it is not possible to benchmark on raw data, it may be meaningful to benchmark with regard to what that value means in terms of performance. This approach has great potential in the realms of decentralising power. For example, local authorities currently report Best Value Performance Indicators to central government, which inform the process of allocating funding. However, it is not logical (and is causing frustration) to rank all authorities by the same criteria; a rural community and a city borough are likely to have very different priorities. By accepting these differences of values and adjusting the value functions to suit it would be possible to make a much more realistic attempt to benchmark performance across the country. The same approach could be applied in a number of sectors.

The other way in which this methodology supports benchmarking is that it allows an organisation to “peg” its own progress year on year. In fact, given the amount of work that is required to review and redraw performance indicators, it is likely that this would be one of the most useful applications of the approach (rather than trying to update the information as it is collected). A monthly, bi-monthly or annual review would be well supported by the model.

Many organisations like to have “up-to-the-minute” information at their fingertips. In this case a tool like Hansen’s Management Dashboard (www.hansen.com) may be appropriate. This works by providing “gauges” (like fuel gauges) of performance:

where good performance sends the arrow spinning into the green; orange warns of dropping performance; and a plunge into the red signifies failure. These tools are complemented by the Perimeta methodology since, without a true understanding of the system and a study of what is important; there is a risk that critical areas of the business may not be monitored. In addition, Step Seven (applying value functions) quickly points out those performance indicators that are not providing useful information.

8.11.3 Gap Analysis

The International Infrastructure Maintenance Manual (IIMM; IAM, 2002) describes a process of gap analysis for determining where improvements to AM practices should be prioritised. This is done through assessing each of the Asset Management Planning components (see Chapter 6) to a score of between 0 and 100. This is done through a qualitative assessment of the current position, then comparing this to the desired score and then “weighting the gap” according to what is considered to be a priority.

The approach described in this thesis supplements the “matrix” approach of the IIMM by enabling the organisation to not only target areas (such as Customer Management Systems, Asset Costing and so on) but to target specific performance indicators within those areas. The schematic view of the system, characterised in the model, built through steps 2 to 7, means that the result of filling “gaps” in monitoring and performance can be visually demonstrated. In addition, the bringing together of performance data through the value functions and figure of merits, is much clearer than a matrix which may require reference to a number of written documents and databases in order to have any real meaning.

8.12 Step Ten: Holding the Gains

Although this process is described in steps, these may overlap with one another, and once all ten steps have been completed, iterations around the steps will be required in order to “hold the gains” (Gillett *et al*, 1996). Some of the work that can be undertaken to maintain the advantage gained in the previous steps is outlined in the following sub-sections.

8.12.1 Knowledge Management

As Plumley (2003) recognises, process modelling can provide an ideal foundation for knowledge management work. Marchend *et al* (2000) contains several examples of Information Management, while Fullan (2001) describes the importance of Knowledge Building.

“If you remember one thing about information, it is that it only becomes valuable in a social context”

Fullan (2001)

While others (e.g. Kaplan and Norton, 1996a; EFQM, 2003) accept this premise, their approaches do not link the system together in the way that can be done through following the methodology outlined here. In particular, the relationship between each process and its parent, all the way up to the organisational mission or vision, is missing.

Through this approach, the problems that industry faces, of developing “corporate amnesia” can be tackled in a structured and systematic manner. Since each process is given an “owner” along with resources, inputs and outputs, the model itself becomes a great vessel for knowledge creation and sharing. While traditional Knowledge Management approaches may focus on producing maps of process flows akin to Ishikawa’s process and flow charts (Bicheno, 2002) it cannot provide the key strength of the Enhanced AM approach described here, which is to prioritise knowledge gathering and capture in those areas that are most critical to the success of the organisation as a whole.

8.12.2 Asset Management Planning

Asset Management (AM) is fast becoming a “buzz” word, particularly in the local authority sector. The process is often driven by the need to procure services, and may be the reason why some of the larger private companies, which have their own maintenance teams, have been slower to pick up on this (in the opinion of the author).

The IIMM (IAM, 2002) argues that one of the key criteria of Best Practice AM will be the knowledge of asset performance and reliability, and of asset value. It goes on to explain that by determining the likelihood and consequence associated with different failure modes, alternative treatment options can be identified, prioritised, costed and implemented.

The enhanced AM methodology takes this one stage further. While the process can be used to support a risk-based view of the world (consequences are propagated through the necessity link; probability increases as “red” increases), it allows for a much more powerful, solutions focused approach. By understanding that an asset has no value except through the service that it provides (Langman, Leicester and Roberts 2003) it becomes clear that even the “best practice” of the IIMM is missing the “big picture”.

A process model, built as described here will enable decision-makers to determine how intervention in any area of the system can lead to gains as well as losses, with regard to overall performance. The methodology captures the likelihood and consequence of “good” (improvement) risk as well as undesirable events.

Managers currently struggle to compose linear reports that describe systemic interventions. The solution is often to break these down into individual reports for “silos” within the business, and the cumulative effect of the “whole being greater than the sum of the parts” is lost. This approach offers the opportunity to begin with the whole and then link this to departmental plans in such a way that the overall objective of AM planning, “linking customer expectations and legislative requirements to determining the optimum operational activities for the business” (IAM, 2002) is not truly achieved.

8.12.3 Filling the Tactical Gap

Rummler and Brache (1995) describe the “Three Levels Framework” for managing organisations:

- Organizational Level (where the strategy is developed);
- Process Level (where processes are designed that will enable the strategy to be carried out); and
- Job/Performer Level (where each job is identified by the outputs and goals required).

The author has come to the conclusions that the names of these levels are somewhat unfortunate, perhaps in that they do not translate well to the UK. Labelling someone as being a “job/performer” or a “process worker” could be as unattractive and demotivating as being referred to as “shop floor” or the dreaded “middle management”. However, she does concur with the statement:

“We have found the Process Level to be the least understood and least managed level of performance.”

(Rummler and Brache, 1995)

The IIMM (IAM, 2002) talks of three levels within an organisation: strategic; tactical; and operational. The AM process broadly falls within the sphere of tactical planning and has, until recently, been overlooked (IAM, 2002). In addition to the advantages offered to AM planning (described above) the methodology described in this thesis can act as a catalyst for closing the “tactical gap”.

By enabling all those within an organisation to identify with one or more processes, the methodology can build confidence and interest amongst staff: a feeling that each job matters. This then breeds a culture where people have pride in their work and wish to communicate ideas and suggestions that could improve the performance of the system. Thus a virtuous circle can be created with operational staff feeding information to their managers on a more regular basis, with the understanding that this will result in improvements and investment where appropriate, rather than blame. The process of building the model can lead to better communication between teams and up and down the management hierarchy, thus bridging any gaps at the tactical level.

8.12.4 Creating a Performance Indicator Cascade

As Figure 8.6 illustrates, performance measurement is the key to stakeholder buy-in, as well as improved delivery. However, there is a downside to performance management, and that is that it can be time-consuming and resources may be misdirected into collecting information and data that does not inform decisions.

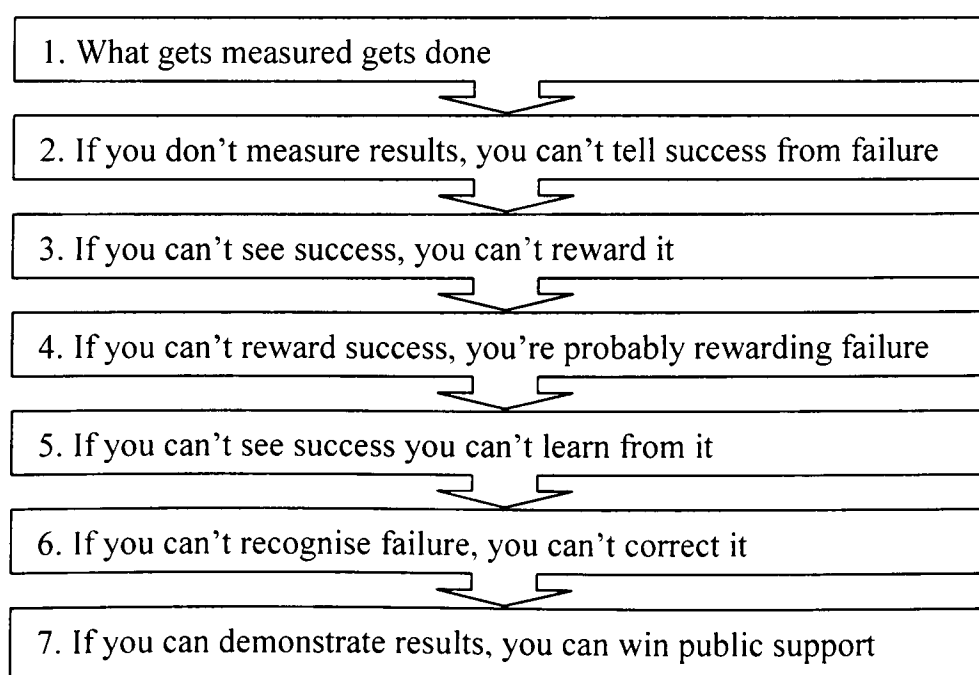


Figure 8.6: “Why Measure Performance?” (Audit Commission, 2000)

In practice, the author has found that most people cannot remember more than 3 or 4 (certainly no more than five) key pieces of information about their job description. Therefore, it seems logical that no individual should be tasked with “managing” more than that number of performance indicators.

At present organisations tend to have a central “Performance Management Team” who “manage” all the performance indicators. That is to say, data is passed to them; they process it in IT systems; and then (perhaps) report it to the relevant person. All of this builds delays into the system and risk mistakes being made and important signals in the data being overlooked.

While the prospect of one person collecting, processing and analysing his or her “own” data from start to finish may not be a practical option, there must be a better method for linking evidence to the decision-maker. This has led the author (through her work with Patrick Godfrey and others at the Highways Agency) to focus on the idea of a performance indicator cascade. The idea of this is that a handful of PIs are reported to an individual at an appropriate level, with action being taken “by exception”. That is to say, when a PI indicates a problem, the person responsible for that PI can “dig down” to the next layer of information; the handful of PIs held by a member of his or her team. Thus, each of, say four, PIs of a parent process may be taken from or derived from one or more PIs from each child. This then shares the burden of reporting and analysing information and reduces the presence of a “blame” culture, by making everyone truly, rather than notionally, responsible for the performance of the system.

8.13 Conclusion

This chapter contains a ten-stage methodology that, it is hoped, will provide an enhanced approach to asset management, bringing together the existing best practice in that field with ideas from risk management, quality management and value management.

A case study is provided in the following chapter, which aims to test and assess this approach and determine whether or not the proposed methodology is workable and provides any advantages over current practice.

9.1 Introduction

The proposed enhanced asset management (AM) methodology, described in Chapter 8, is the result of a case study at Scottish and Southern Energy plc (SSE), combined with further work carried out in industry following the completion of the initial period of research. Each of the ten proposed steps is described, even though some of these steps emerged after the original case study had been completed. Following on from this research it was found that ten steps were too many to be remembered by most project teams, and the ideas were condensed to the five steps of the Performance Improvement Cycle (PIC), described in Appendix D. The development of the PIC has been an iterative process, and has been driven by the author, with support from colleagues at FaberMaunsell. It has developed organically through a series of projects in several sectors, and was finally captured as a five-stage process by the author. The relationship between the ten-step enhanced asset management methodology and the PIC is shown in Table 9.1.

| Table 9.1: Relationship between enhanced AM methodology and the PIC | | | |
|---|---|--------------------------------|-------|
| Step | Enhanced AM Methodology | Performance Improvement Cycle | Stage |
| 0 | Preparation | What do we do? | 1 |
| 1 | Laying the foundations | | |
| 2 | Scoping stakeholder requirements | | |
| 3 | Building the process model | | |
| 4 | Adding the weightings & prioritising evidence needs | What is important? | 3 |
| 5 | Checking the model | | |
| 6 | Assembling the evidence | What do we measure now? | 2 |
| 7 | Applying value functions | | |
| 8 | Associating evidence with model | | |
| 9 | Understanding and reviewing | Where are the gaps/priorities? | 4 |
| 10 | Holding the Gains | Continuous Improvement | 5 |

Stages 2 and 3 of the PIC approach (and equivalent steps) are interchangeable and generally progress alongside one another, depending on the focus of the project team. Each of the steps is described in more detail in the remainder of this chapter.

9.2 Step Zero: Preparation

During the initial research with SSE, the preparation stage was not carried out in any formal manner. However, the extensive background reading, work-shadowing and other research described in Chapter 3 did lead to a thorough understanding of the issues faced by the company.

9.3 Step One: Laying the foundations

The support of the organisation was established through project workshops as part of the CMAM research project. In addition, the author made several trips to Scotland to visit the civil engineering department. Due to the research focus of the work, rather than a business-based project, the more formal aspects, such as establishing a physical project space and establishing a high performance team, were not addressed. The benefits of the research from the point of view of SSE were clarified and developed throughout the course of the project.

9.4 Step Two: Scoping Stakeholder Requirements

Following consideration of the level of depth and width at which the processes within SSE should be explored (see Chapter 3), it was decided that a ‘T’-shape model should be produced. The benefit of this is that the width at the top ensures that none of the key, strategic goals of the organisation are overlooked (thus helping to avoid the problems of local optimisation), while the depth in one area ensured the following:

- The organisation was not overwhelmed by the size of the task;
- Benefits of process-modelling could be quickly demonstrated; and
- The work can be extended later

Before any process model of the system can be built it is first necessary to decide on the boundaries of the system. Reviewing the systems literature, described in Chapter 6, revealed that the boundaries could be defined as the place in which stakeholders interact with the system. Therefore, these boundaries depend on the stakeholders to be considered.

The key stakeholders that act on a hydro-electric company, such as SSE are:

- Customers;
- Shareholders;
- Staff;
- Neighbours;
- Regulators (such as the Environment Agency or SEPA; Scottish Environment Protection Agency); and
- Campaigners.

If the success path is defined as that which results in the stakeholders being satisfied then the first step must be to identify the stakeholder that is to be satisfied. This is not trivial and may involve constructing a number of models to gain a full understanding of the interaction between the stakeholder and the system. Figure 9.1 is an example of a use case model of the Customer interacting with the electricity generator, via a marketing organisation.

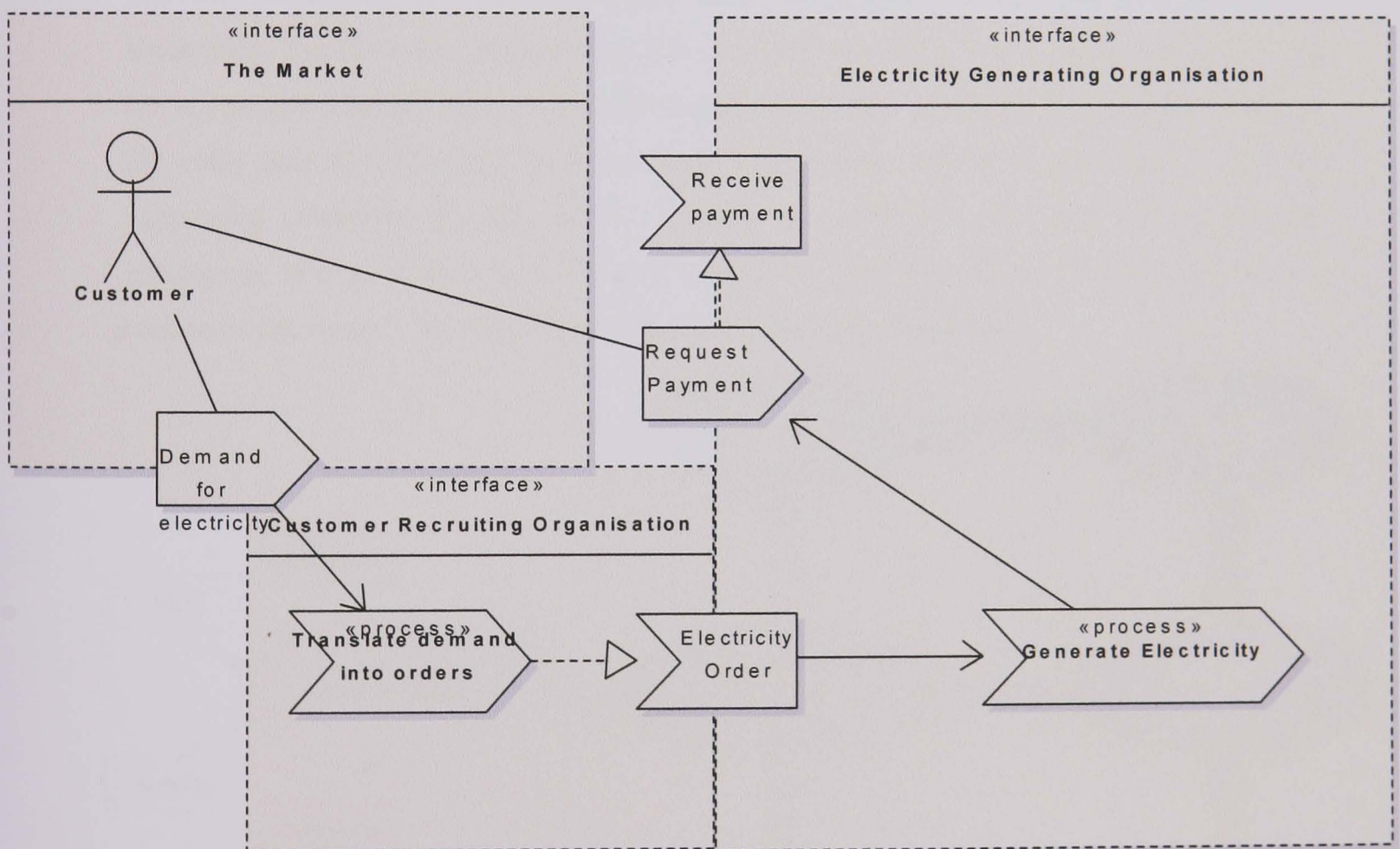


Figure 9.1: Use case diagram of customer interacting with the organisation

Over time it became clear that there were a number of stakeholder interactions with the organisation, and the difficulty became trying to discover how these could be “translated” into the model. The author spent a good deal of time experimenting with generic holons that contained different key elements, such as resource stores, “banks”, “management” and so on. These reflected the ideas expressed in the UML Business Model, Beer’s VSM and the Rummler and Brache model template. However, it soon became clear that, while these

models might be useful conceptually, they were too complex for a model that took various stakeholder views into account.

Ultimately, the author moved towards a model that was apparently very simple, although the complexity is recorded in the tabs in the holon information panels (in Perimeta/CMAM). The final model follows this premise:

The demands and needs of the various stakeholders are translated by the organisation into a mission and vision (purpose); this is then passed down the layers to the level at which it can be delivered.

Reading of Goldratt’s work (1993,1996, 2000) suggests that the primary goal of a company is to make money. The author suggests that not for profit organisations have similar demands to businesses; with the taxpayer taking on a similar role to that of a shareholder. Essentially, the customer demands the effective delivery of services, while the shareholder (or tax payer) demands that they be delivered efficiently. Goldratt (1990, 1996) states that the main goal of a company is to “make money now as well as in the future”. The two supporting conditions for this are to “Provide a secure and satisfying environment for employees, now as well as in the future” and to “Provide satisfaction to the market now as well as in the future”. In other words, the system must be sustainable.

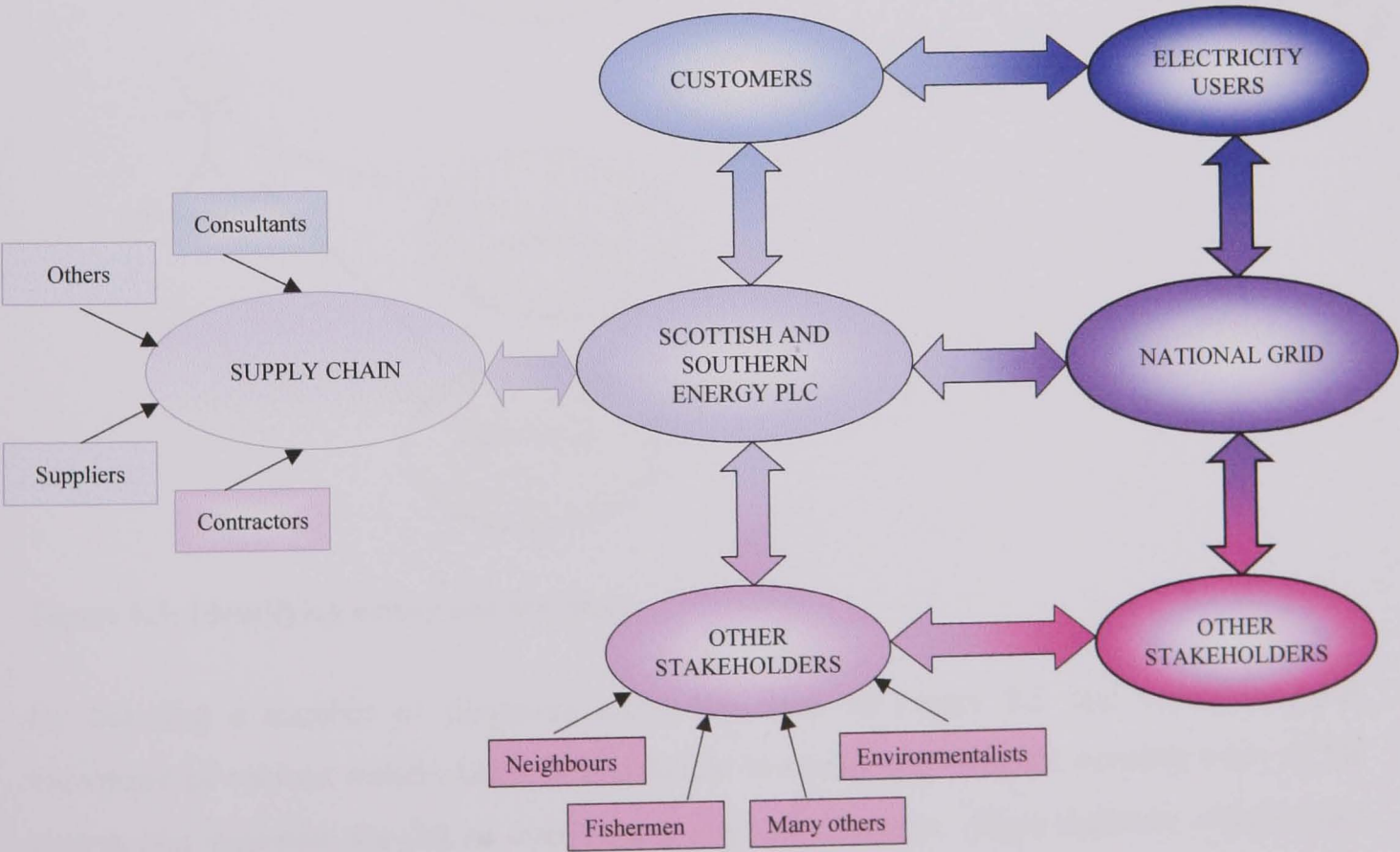


Figure 9.2: Model of Stakeholders acting on SSE

Figure 9.2 shows a model of some of the stakeholders that act on SSE and how these are passed onto the supply chain. The UML was used to generate initial ideas of “actors” who interact with the system through “use cases” (Figure 9.3). These are described in more detail in Table 9.2.

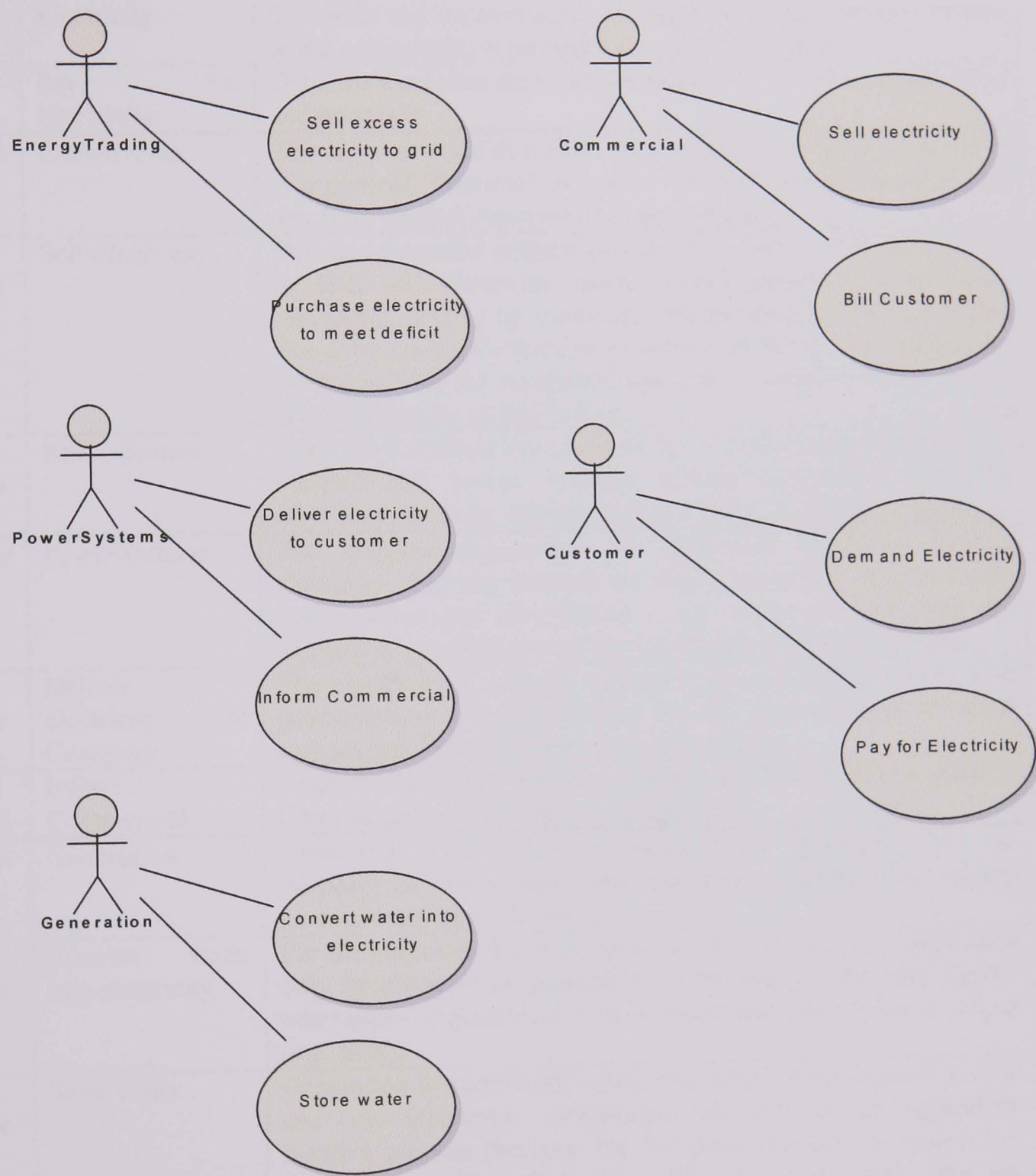


Figure 9.3: Identifying actors and use cases

By building a number of diagrams along the lines of Figure 9.3 and considering the viewpoint of various stakeholders, it is possible to ensure the broadest possible view of the system and minimise the risk of overlooking any key elements. Since different stakeholders will have varying, sometimes conflicting, views of what they require from the system, it makes sense for the modellers to interpret these through the mission and vision.

Table 9.2: Actors and Use Cases (Version 1)

| | Name | Description |
|----------|--------------------------------------|--|
| Actor | Customer | <i>The end user who receives the electricity generated by the company.</i> |
| Use Case | Demand Electricity | This is the use case that initiates the relationship between the Customer and the company. On the whole, the Customer relates to the commercial department as a point of contact. |
| Use Case | Pay for Electricity | Once the Customer receives the electricity it will be billed for it and must pay. |
| Actor | Commercial | <i>This is the division that deals with billing - it could be equivalent to a general "financial" process - however, the difference is that this is an explicit department in the company.</i> |
| Use Case | Sell Electricity | This has a parallel process (use case), which is "bill Customer". In fact, sell electricity could include approaching potential customers, setting up contracts, billing the Customer, chasing bad debt, taking Customers to court and so-on - on the whole, we begin with the successful use case - rather than the "when good Customers go bad" cases. |
| Use Case | Bill Customer | Once the Customer has received the electricity and this has been verified (by power systems telling commercial that the electricity has been delivered) then a bill is sent to the Customer. |
| Actor | PowerSystems | <i>The division responsible for delivering electricity to the Customer. For this example we shall assume that they deal with transmission and distribution - e.g. every process from the moment of generation until the Customer receives the supply.</i> |
| Use Case | Deliver electricity to Customer | The electricity is actually passed to the Customer via the grid (transmission and distribution) but for this example we shall assume that PowerSystems does this directly. |
| Use Case | Inform Commercial | Once the electricity has been delivered, PowerSystems informs Commercial so that a bill can be sent out. |
| Actor | Generation | <i>Generation turns a fuel into another type of energy. For the purposes of this example this has been simplified into merely turning water into electricity.</i> |
| Use Case | Convert water into electricity | For the purposes of this example we shall assume that generation only involves hydro-generation of electricity. We shall ignore other types of generation (e.g. thermal) and other types of output (e.g. heat). |
| Use Case | Store water | Generation includes civil assets - therefore, store water is a valid use case (process). Sometimes this may be an apparently inactive process (because the infrastructure already exists) but the process will include the safety of the elements that are required in order to store water. |
| Actor | EnergyTrading | <i>EnergyTrading assesses whether enough electricity is being made to meet the demand and buys and sells electricity accordingly.</i> |
| Use Case | Sell excess electricity | If the company generates too much electricity then the EnergyTrading will sell it to the grid at a premium (if others have not met the trading agreement). |
| Use Case | Purchase electricity to meet deficit | If the company generates insufficient electricity to meet Customer demand then the company must purchase it from the grid. This is not the best situation as it is very expensive to do this. |

The next step taken was to write down a concise description of the problem domain. The nouns are underlined (the first time they appear) in order to identify the potential classes. Italics are used to identify processes. This technique is taken from the UML (e.g. Larman, 2002).

The Customer is the person who *receives the electricity generated by the company*. The Customer *demand*s electricity from the company. The customer contacts the company via the Commercial department as a point of contact. The Commercial department *agrees a contract* with the customer to *deliver electricity* in accordance with the terms of the contract. Electricity is delivered to the customer by the Power Systems department. Once the customer has received the electricity and this *has been verified* (by power systems telling commercial that the electricity has been delivered) then a bill is *sent* to the customer by the Commercial department. The customer then sends a payment to the Commercial department. The Commercial department can also *approach potential customers*, *set up* contracts, chase up bad debt, *take customers to court* etc.

For this example we shall assume that the Power Systems department includes the processes involved with they deal with transmission and distribution (via the Grid) - e.g. every process from the moment of generation until the customer receives the supply.

The Generation department *generates* the electricity by *turning a fuel* into another type of energy. For the purposes of this example this has been simplified into merely turning water into electricity. We shall assume that generation only involves hydro-generation of electricity and ignore other types of generation (e.g. thermal) and other types of output (e.g. heat).

The Generation department *looks after* the civil assets, which carry out several processes, including storing water. The department is responsible for the safety of the elements that are required in order to store water and to generate electricity.

The EnergyTrading department assesses whether enough electricity is being made to meet the demand and *buys and sells* electricity accordingly. If the company generates too much electricity then EnergyTrading will sell it to the Grid at a premium (if other gernerators have not met the Trading Agreement). If the company generates insufficient electricity to meet customer demand then the company must purchase it from the grid. This is not the best situation as it is very expensive to do this.

Continuing along the lines of UML work (Larman, 2002) the next stage is to discard:

- Nouns that are repeated synonyms (e.g. Person is the same as Customer);
- Nouns that are really events rather than objects (e.g. Payment);
- Nouns that are really states (e.g. “bad debt” or “credit” are states of the class “balance”); and
- Nouns that are only actors indirectly (e.g. “Other Generators” only impact on the Company via “The Grid”).

The list of probable “classes” that remain is shown in Table 9.3.

Table 9.3: Probable Classes (following the first iteration)

| Class | Description |
|---------------|---|
| Customer | The end user who demands, receives, and pays for, electricity |
| PotCustomer | A potential customer |
| Electricity | The product manufactured by TheCompany and supplied to the Customer in return for payment |
| TheCompany | A simplified hydro-electric generator that generates electricity and sells it for a profit |
| Commercial | The department within the company that deals directly with the customer (particularly the processes related with billing) |
| Contract | A document that the Customer and TheCompany both sign as a legal agreement regarding the terms of supply of electricity and payment |
| EnergyTrading | This department within TheCompany coordinates demand for Electricity with TheGrid and decides the amount TheCompany should generate |
| PowerSystems | The department within the company that delivers electricity to the customer |
| Bill | The document that TheCompany delivers to the Customer requesting payment for Electricity supplied |
| Account | A database where the details relating to the transaction between the Customer and TheCompany (balance, supply etc.) can be stored |
| Generation | The department within TheCompany that converts the Fuel (in this case Water) into Electricity |
| TheGrid | An external actor with which EnergyTrading negotiates to buy and sell electricity on behalf of the company (as required) |
| Fuel | Any resource that is used by TheCompany in order to generate Electricity (in this case it is just Water, but could be extended later) |
| Energy | This is a superclass that currently includes Electricity but could be extended to included PE, KE, or Heat as required. |
| Water | The type of ‘fuel’ that is used by a hydro-electric company in order to generate electricity |
| CivilAsset | The concrete objects that are required in order for TheCompany to be able to convert water into electricity (e.g. dam, power station etc.) |
| Element | A superclass that includes various assets (mechanical, electrical and civil) that are required by TheCompany in order to generate electricity |

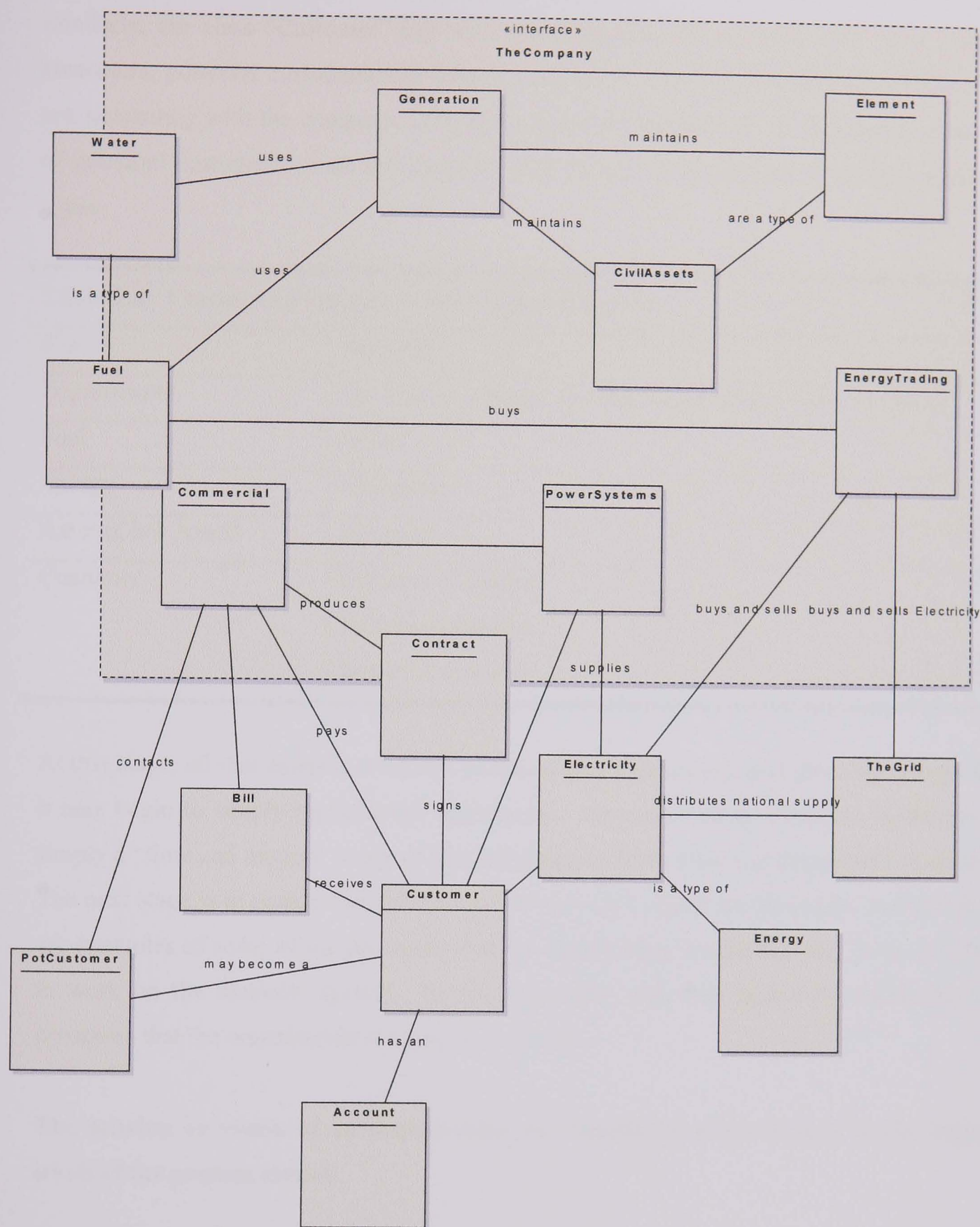


Figure 9.4: Class model showing basic classes first considered in the case study

The class model shown in Figure 9.4 was refined further through the course of the case study. A simplified list of objects and classes was developed as a result of this work (Table 9.4). An additional class “Department” has been added because Generation, EnergyTrading, PowerSystems and Commercial are all departments. Thus, they are likely to have several characteristics in common, for example: management team, employees, budget. It may be that some of the data relating to the departments may be held centrally by the company, in which case it may be necessary to change the layout of this part of the diagram later.

Similarly, the class “Customer” has been added because the company may have existing customers, potential customers and former customers. Currently the former customers are not interacting with the company, although it could be that they are in fact merely a sub-set of potential customers, since the company will be attempting to have them as a customer again.

Table 9.4: Classes and Objects in the Logical Diagram

| Class | Objects |
|---------------------|--|
| Departments | Generation, Energy Trading, Commercial, Power Systems |
| Fuel | Water |
| Energy | Electricity |
| Asset (Civil Asset) | Element |
| Customer | Potential Customer Existing Customer Former Customer |

At this stage, all that exists is a “static” model of the organisation, and there is a danger that it may begin to simply replicate the organigram. This can lead to a process model that is simply a “time and motion” study of how information flows from one department to another. The next stage is to realise that the arrows between each object are processes, and that these are examples of some of the processes that the organisation is carrying out. Next, it is time to work on the dynamic system. In the case study, this was begun by stating the key processes that the organisation is trying to carry out.

The mission or vision of an organisation can usually provide the key to the highest levels of the process model.

The model was built for a simplified hydro-electric company, described as follows:

The company generates electricity by storing water (PE), then using it (KE) to turn a turbine (KE) to generate electricity (EE) - which is given to the customer (directly) in return for payment. The company has one generation set next to one reservoir on one river, which was created through the construction of one dam.

The dynamic model can be based on a sequence diagram, which is rather like a flow chart (see Figure 9.5). This can also be represented as an activity diagram (Figure 9.6), however, the danger of this is that it can also be used to divide processes into different silos (of departments). As long as it is recognised that some of the processes will sit on the

“boundary” of two swimlanes this approach could also be adapted to support a Knowledge Management project. Therefore, while the UML diagrams can help stimulate ideas, and are ideal for capturing stakeholder requirements, the mixture of FAST and hierarchical diagrams was much more useful for developing the process model.

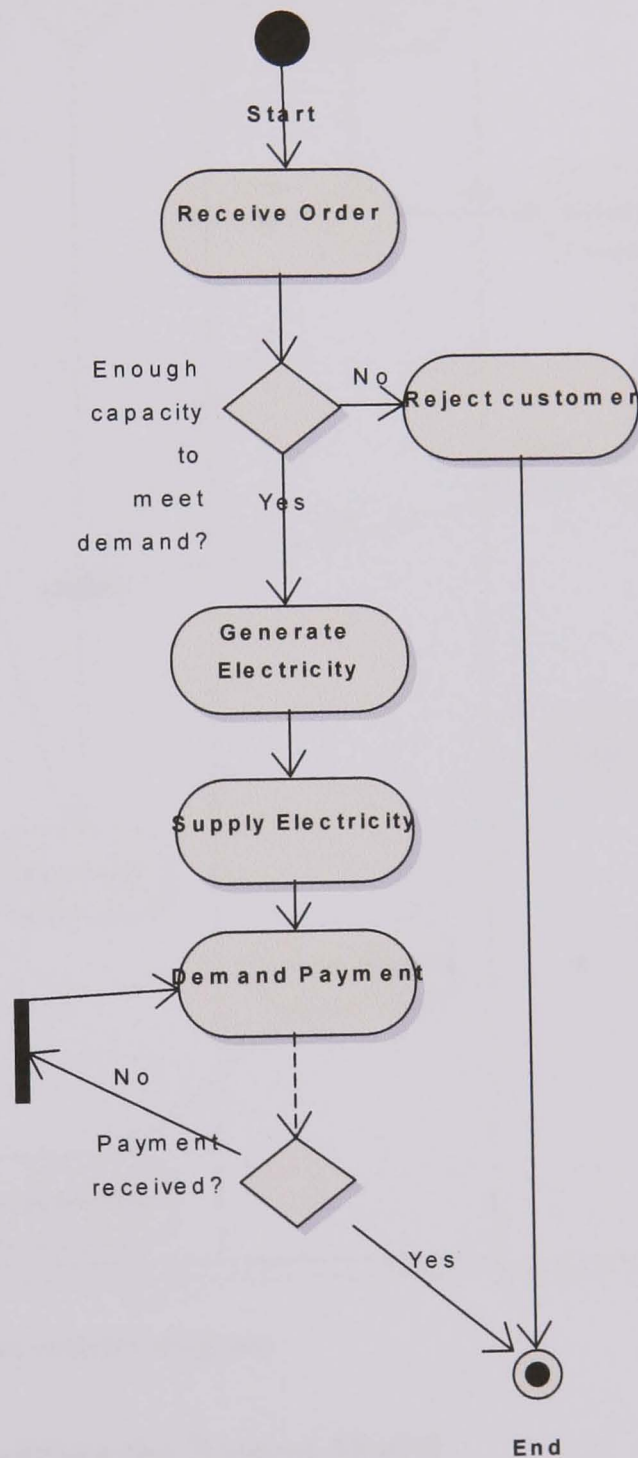


Figure 9.5: Example of a sequence diagram

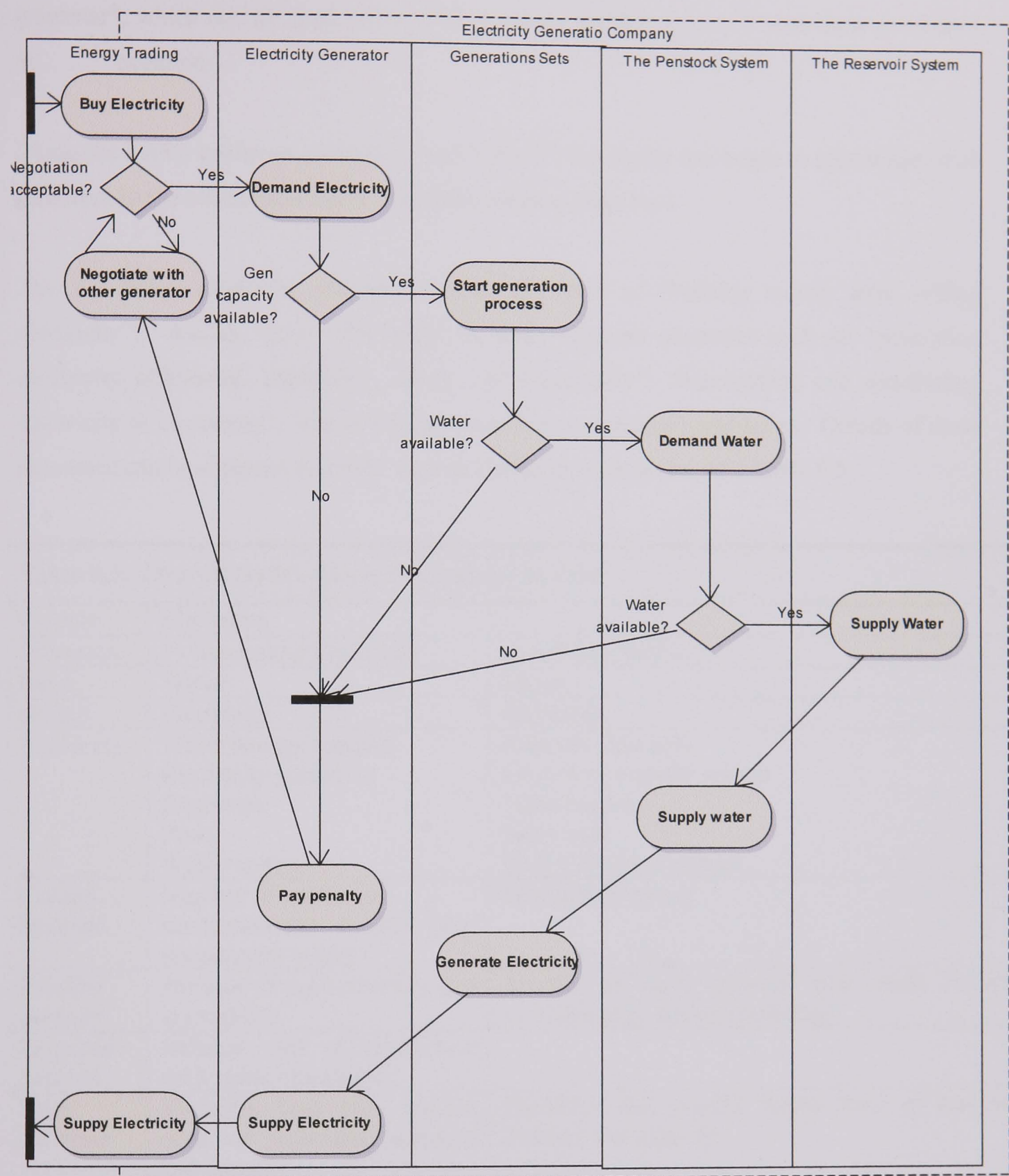


Figure 9.6: Example of an activity diagram

9.5 Step Three: Building the Process Model

The case study involved many attempts to model the processes within the organisation. One of these was published in an early paper (Hall *et al*, 2001). As has been described in the previous chapter, experiments were made into “POPES” (Performance –Orientated Physical Entities), but this led to a diversion from true process principles, because of too much focus on physical elements. It was through several iterations in the case study that the “new

grammar”, which can fill gaps in the “how good are we/they at.....?” and “how good am I at.....?” questions.

Using the FAST questions of “How?” and “Why?”, the model can begin to take shape, with reference to the stakeholder needs established during Step Two.

The top holon might be something along the lines of “Making money from selling electricity”. Asking “how” this might be done suggests processes such as “generating electricity efficiently, effectively, safely and sustainably”; “transmitting and distributing electricity to customers”; “collecting payment from customers”; and so on. Details of these processes can be captured in a tool, such as Perimeta, or in tables, like Table 9.5.

| Table 9.5: Overall Hydro-Electric Company System | | |
|--|---|---|
| Product | Electricity | |
| Processes | 1) <i>Generating</i> Electricity | 2) <i>Selling</i> Electricity |
| Input | Water | Money |
| Output | Electricity | Electricity |
| Resources | Water storage capacity Electricity generator Engineers Pipes Waste system | National Grid cess Electricity transfer system Transformers Sales team Cash collection system |
| Current Demand | Number of customers Environmental factors (e.g. government policy) | Willingness to pay |
| Possible capacity | Amount of each resource that is available | Amount of each resource that could be made available (e.g. through building) |
| Required demand | Balance cost of production with value of product | |
| State variables | Variables that give current state of resources, demand and capacity | Variables that predict future state of resources, demand and capacity. |

This methodology seems extremely simple, but a good deal of skill is required to avoid the numerous “dead ends” that can occur. However, it certainly provides a more practical approach than trying to expand the ideas of the business process models of Beer (Flood, 1999) or Rummler and Brache (1995), as can be seen from Figure 9.7, which is an adaptation of the Rummler and Brache method.

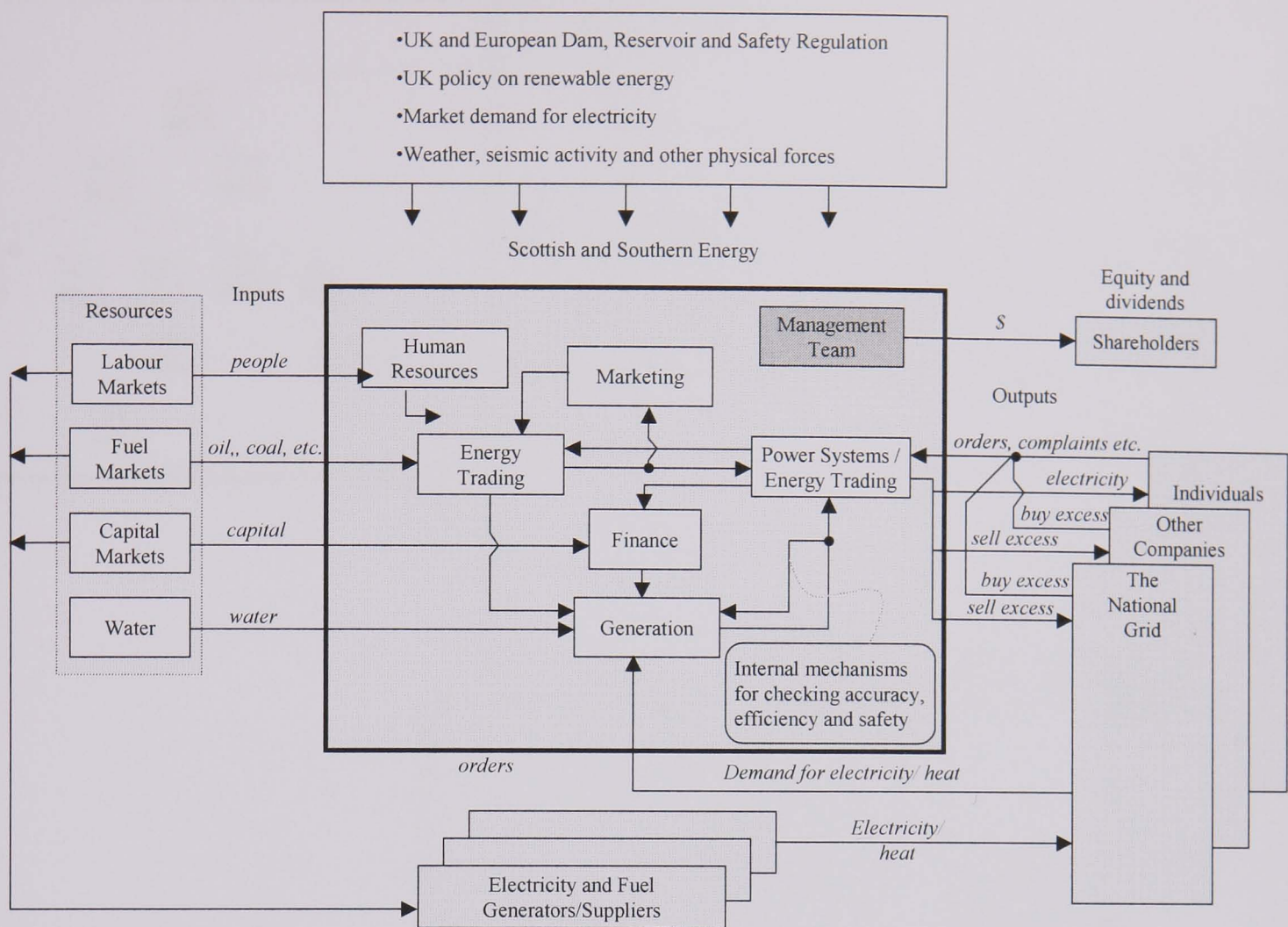


Figure 9.7: An attempt at using Rummler and Brache's (1995) methodology

This more complicated model might be appropriate for a complex Enterprise Resource Planning programme, but is not necessary for the purposes of this work, which have the goal of identifying the performance of the system. The attempt to link different parts of the business can lead to complexities because feedback loops and two-way interactions (such as “buying” and “selling”) can be difficult to capture.

In addition, the existing models tend to be unrealistic since they do not show how human resources (and training) and the management are linked to the rest of the system. Because this model works by passing all stakeholder requirements through the top-level strategy or vision it is perhaps a more robust methodology for ensuring that these, sometimes conflicting, needs are met.

The model produced through this methodology is shown in Figure 9.8. Individual sections are magnified in Figures 9.9a to 9.9e. The fact that it is difficult to reproduce these models such that they are legible is in itself a justification for the use of a tool such as Perimeta, which enables the user to quickly navigate around a large model using the “folder” view, given in Figure 9.10.

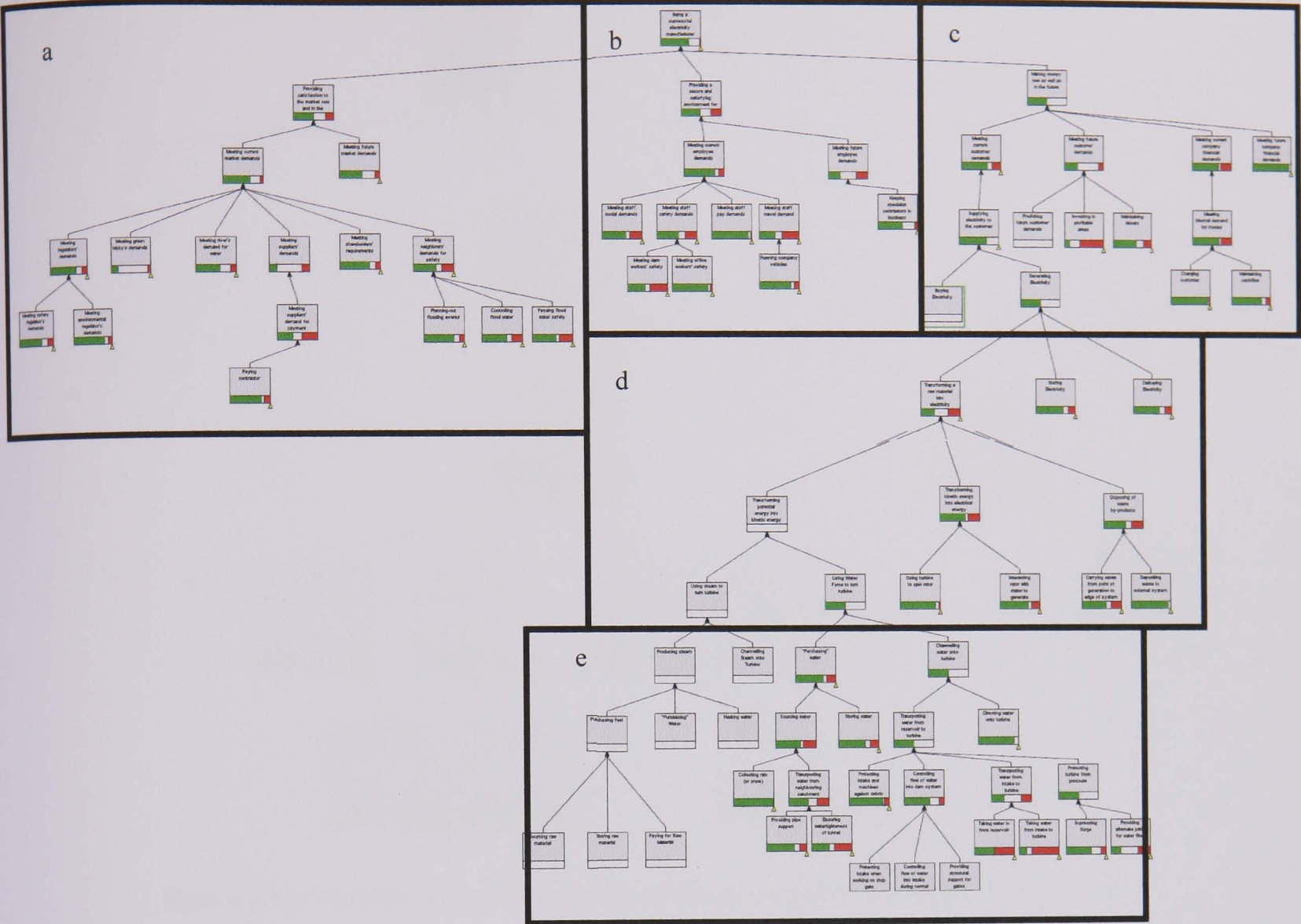


Figure 9.8: The Complete Case Study Model

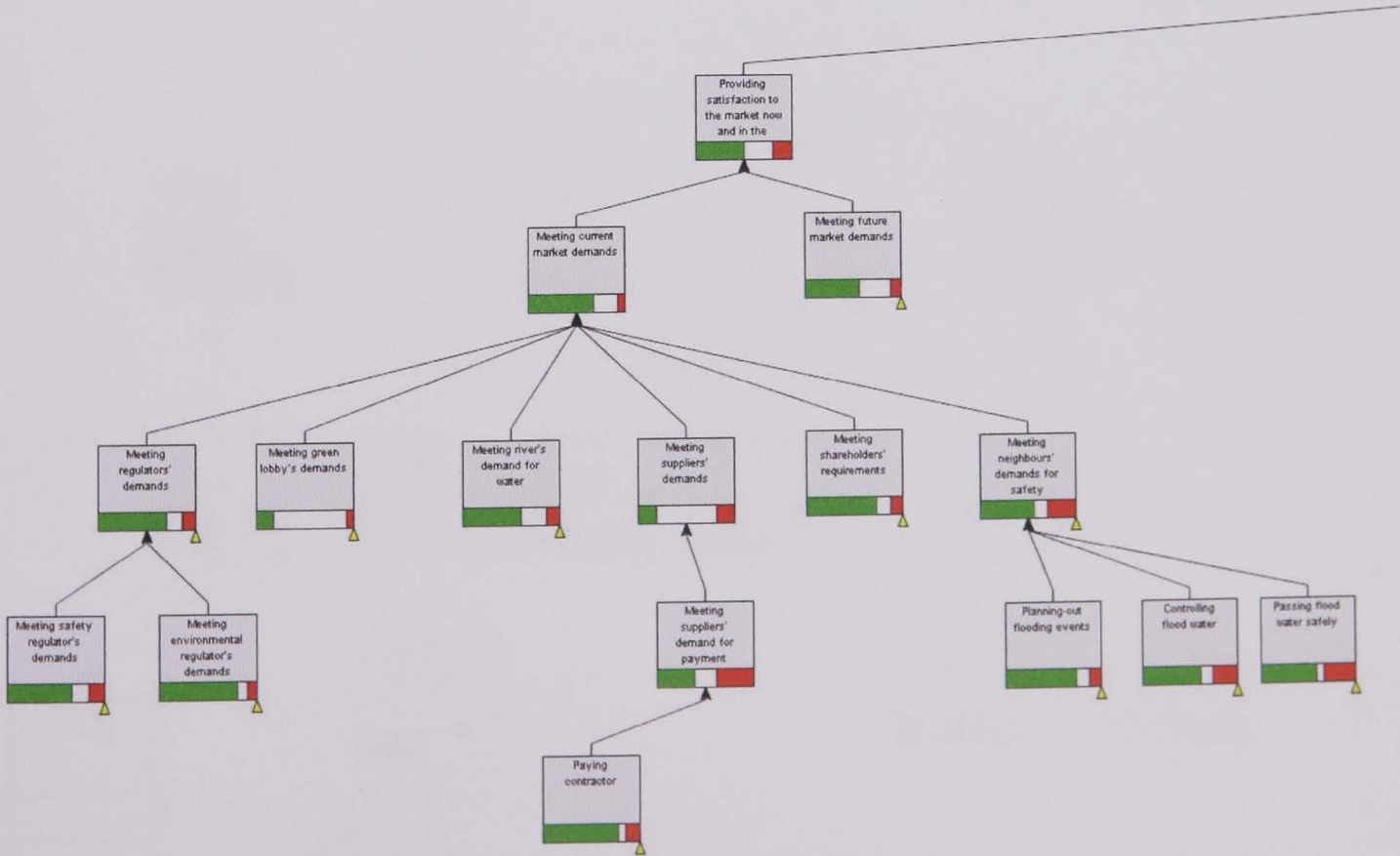


Figure 9.9a: "Providing satisfaction to the market – now and in the future"

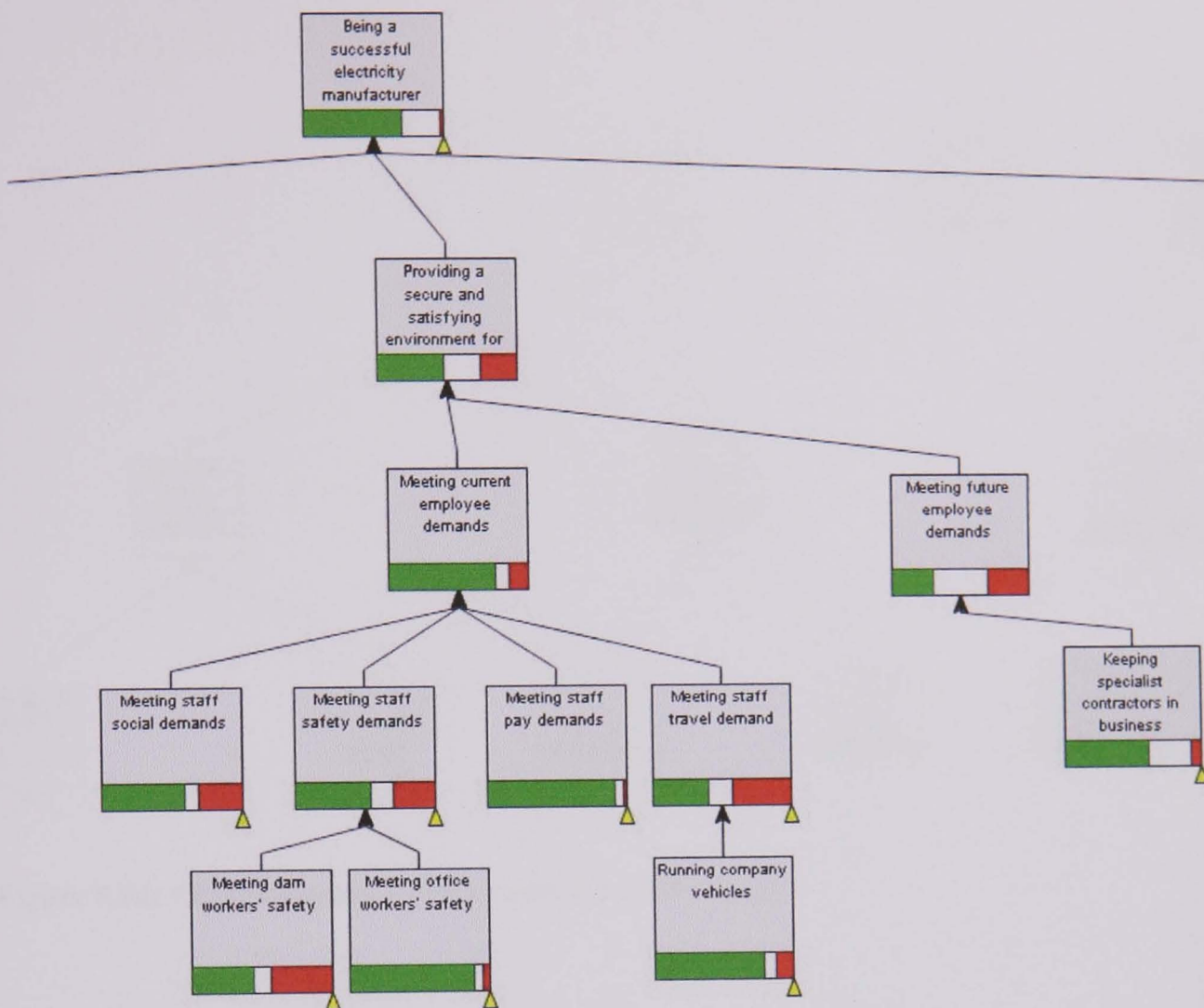


Figure 9.9b: "Providing a secure and satisfying environment for employees"

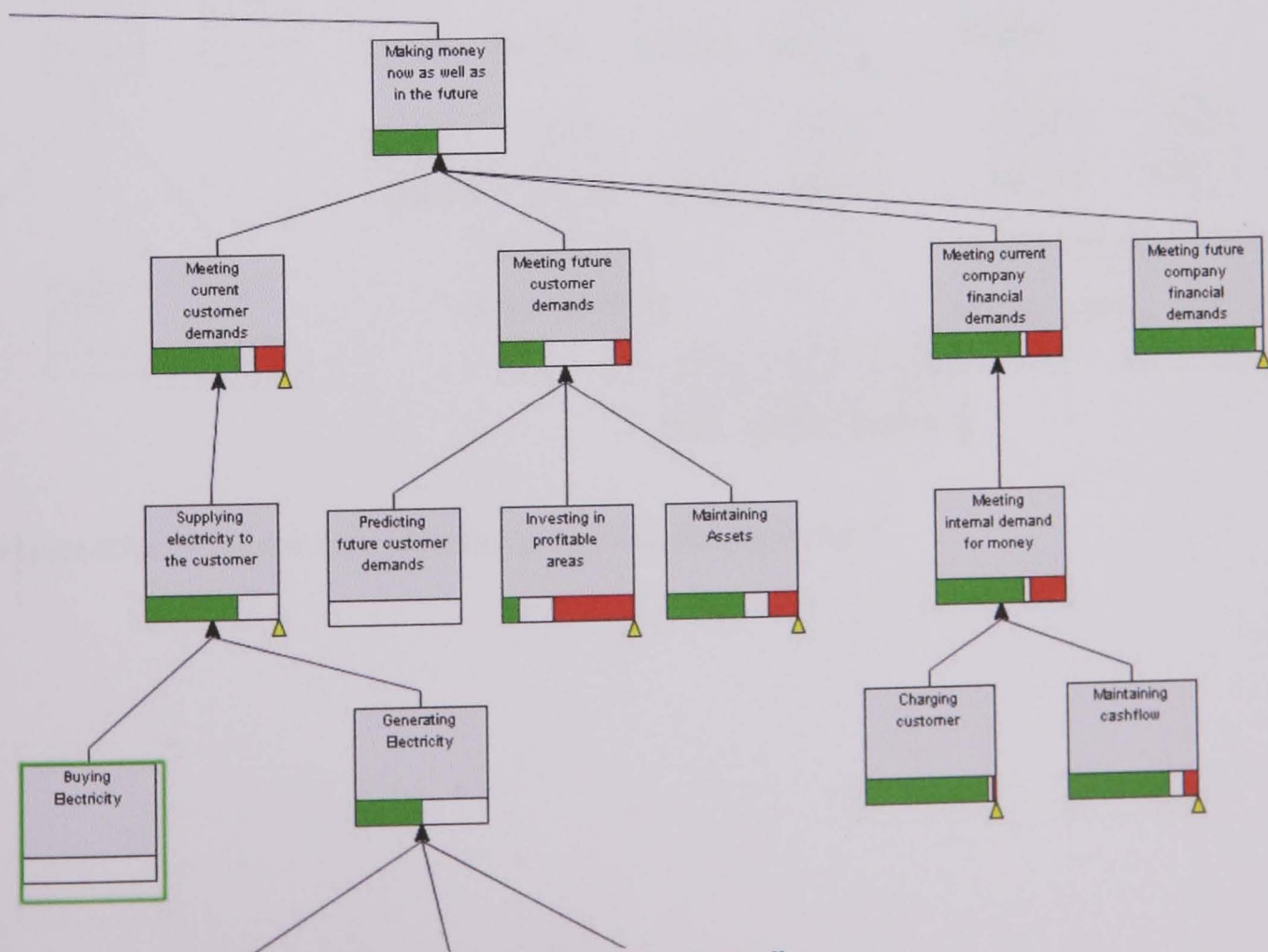


Figure 9.9c: "Making money now as well as in the future"

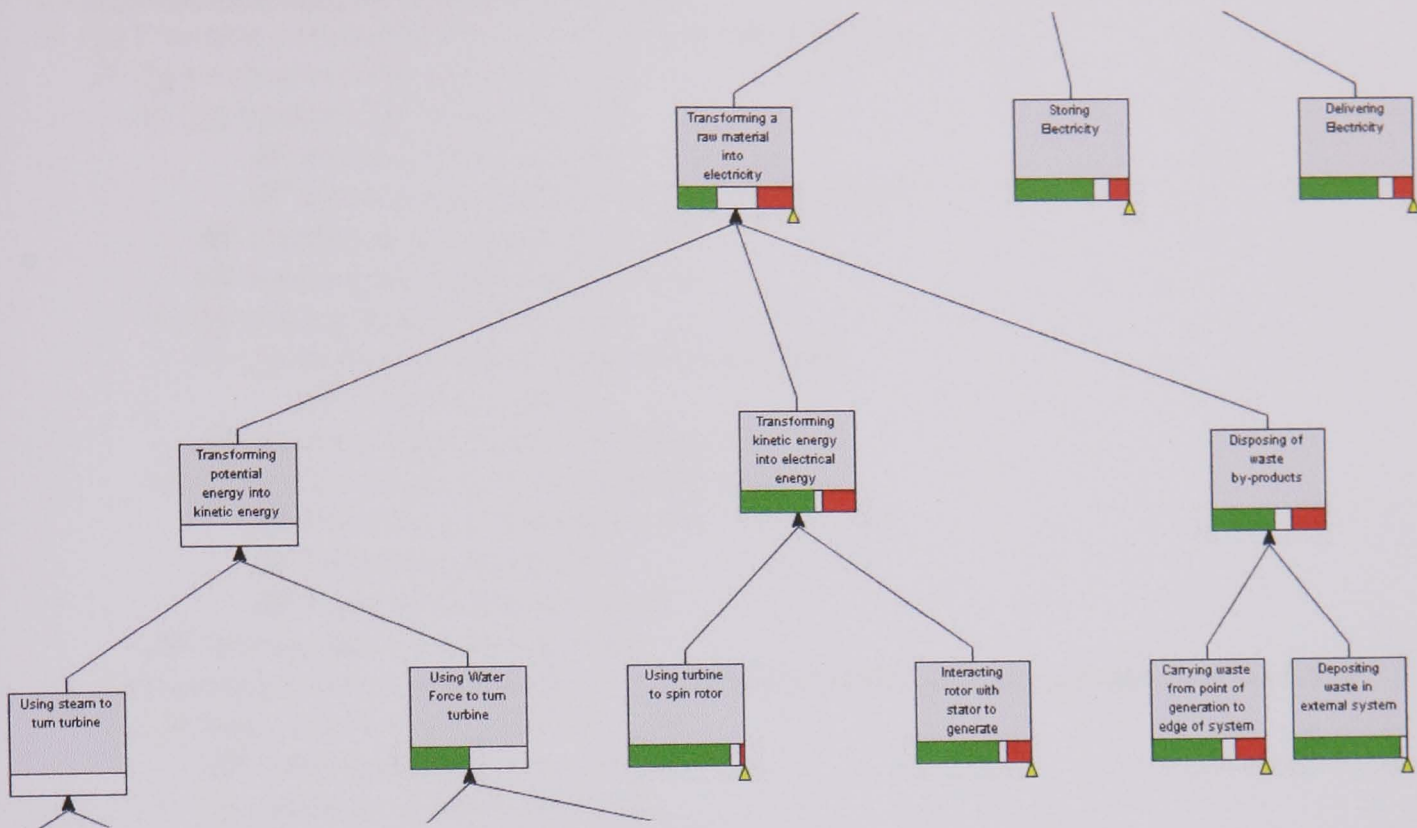


Figure 9.9d: “Transforming a raw material into electricity”

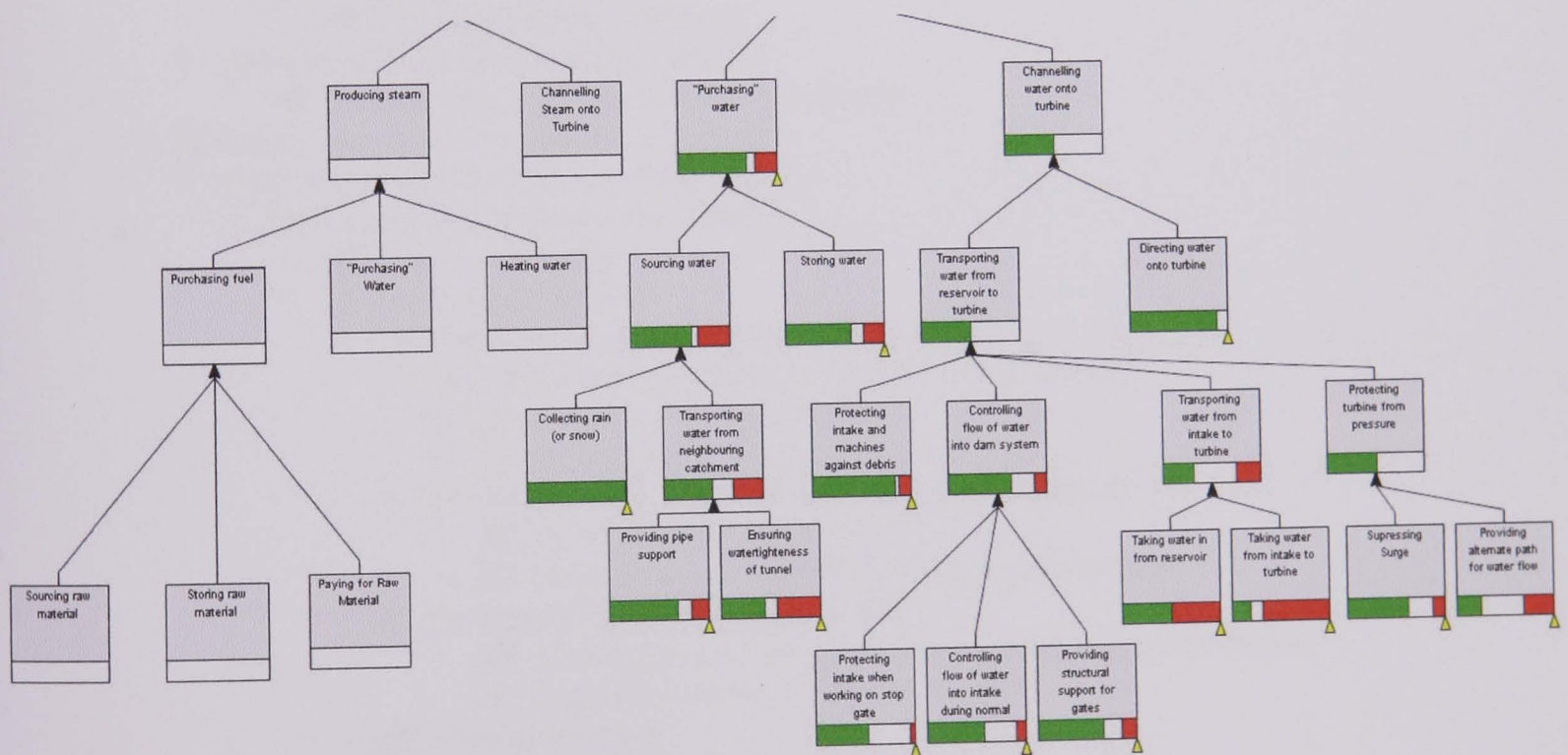


Figure 9.9e: “Transforming potential energy into kinetic energy”

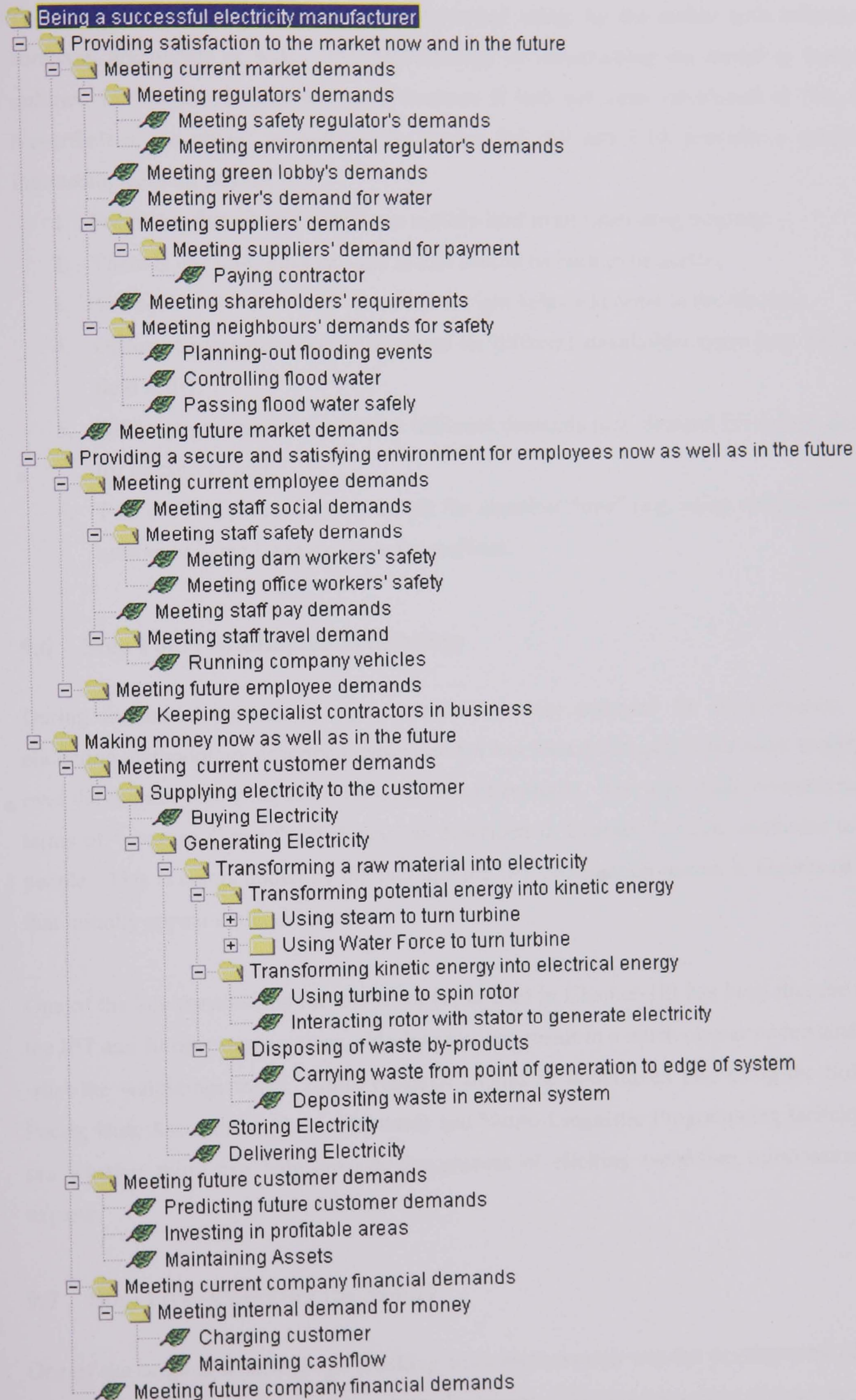


Figure 9.10: Expanded "folder" view of processes

The case study model was essentially constructed solely by the author with reference to company documents at SSE. The methodology of constructing the model in teams, as outlined in Chapter 8, was not used because it had not been developed at that time. Nevertheless, the model, as outlined in Figures 9.8, 9.9 and 9.10, provides a number of interesting learning points:

1. Following “how” and “why” can rapidly lead to an interesting diagram;
2. There is no “one” answer – the model should be built to be useful;
3. The convention of “when” from left to right helps add order to the diagram;
4. Different processes may be involved for different stakeholder types (e.g. office and field staff);
5. Different processes may deliver different demands (e.g. demand for safety; demand for transport); and
6. Two or more processes may satisfy the question “how” (e.g. using water to drive the turbine or using steam to drive the turbine).

9.6 Step Four: Adding the Weightings

During the initial case study equal weightings were assumed for all processes. The elicitation methodology described in Section 8.6 has been developed in the work undertaking over the months following the original course of research. The case study revealed that the terms of “necessity” and “sufficiency” as described in Chapter 7, cause confusion to most people. This is compounded by the fact that the IPT propagation results in Figures of Merit that initially appear counter-intuitive.

One of the key conclusions for this work (described in Chapter 10) has been that the use of the IPT and Juniper propagations, side-by-side, can result in a much clearer understanding of what the weightings mean. More research should be undertaken into using the Solutions Focus, Risk Assessment (failure-focused) and Neuro-Linguistic Programming techniques to see whether these can help smooth the process of eliciting weighting information from experts.

9.7 Step Five: Checking the Model

One of the original contributions resulting from this research was the development of tables for checking the flow of logic throughout the model. This has been done through the use of tables to capture the flow of demand and response through this system. An example is given in Table 9.6, and further examples can be found in Appendix C

Customer Interactions

The **customer** asks the *electricity supplier* to supply it with electricity in accordance with his requirements. The *electricity supplier* agrees to supply the **customer** with electricity according to their conditions. The **customer** agrees to the *electricity supplier*'s conditions. The *electricity supplier* supplies the electricity according to the **customer**'s requirements. The **customer** pays for the electricity according to the *electricity supplier*'s conditions.

Table 9.6: Demand and Response for Customer/ Electricity Supplier Interaction

| Primary actors | Interests |
|--|---|
| Customer (customer) | Wants to receive electricity according to his requirements |
| <i>electricity supplier (organisation)</i> | Wants to make money from selling electricity according to its conditions. |
| Precondition | The customer identifies a need (from external stimuli) for electricity |
| Success guarantee (post condition) | Customer has received electricity according to his requirements and <i>company</i> has received payment according to its conditions. |
| Shadow usage cases | Customer – <i>customer complaints watchdog</i> . Customer complaints watchdog to <i>company</i> . |

Table 9.7: Demand and Response for Customer/ Electricity Supplier Interaction

| | Prompts | Customer Requirements | Electricity Supplier Requirements |
|---|--|---|---|
| 1 | What do I need from this transaction? | Electricity | Money |
| 2 | How much of it do I want (from this transaction)? | Enough to light my home when I want to and keep it warm (XkWh) | Enough to pay shareholder dividends at Y%, pay staff, service loans and pay for repairs and bills – Cost + £X per kWh |
| 3 | When do I want it? | On demand | Monthly payments by direct debit or quarterly within 7 days of billing (after use) |
| 4 | Where do I want it? | At the 'plug-face' | In my bank account. |
| 5 | How do I want it (quality)? | Ready-generated and of a steady voltage through the mains | Regularly, paid-in full, preferably before supply, but if not within 7-28 days after |
| 6 | How much will I give for it (depends on values and perceived level of need)? | A bit extra for renewable - or no more than British Gas – or no more than my best friend. | The required amount of electricity, up to a limit of ZkWh between bills being paid. |
| 7 | Why do I need it (why do I value it)? | I want to be able to see in the dark and be warm in winter | If I don't earn more than costs then eventually I will go bankrupt and people will lose their jobs. |
| 8 | Who will I get it from? (linked to 6) – preferred supplier | Green supplier – well-known company – cheapest on market | People on medium to high incomes with big houses and good credit ratings |

Table 9.8: Demand and Response for Customer/ Electricity Supplier Interaction

| Prompts | | Customer Constraints | Electricity Supplier Constraints |
|---------|--|--|--|
| 1 | What is prompting me to carry out this transaction? | Need for light – pointed out by bumping into furniture. | The bank is charging £Xm in interest on my borrowings and I need to pay the bills and salaries |
| 2 | What is my capacity for using and storing the product? | Enough to heat all my radiators to max and light all my lamps | I don't want to earn more than £Xm in one year or I'll be clobbered by tax |
| 3a | When is the earliest that I can get it? | Now | By direct debit one month before supply or within 7 days after |
| 3b | When is the latest I can get it? | Just before I get pneumonia | If they don't pay within 28 days of supply I instigate the "sue" usage case. |
| 4 | Can I have it where I want it? | Yes, my home is connected to the mains | Preferably by direct debit direct to my account, or else by check |
| 5 | What quality is available? | I can check with the Which? Guide to see which company offers the best service | My competitors have nicked the best customers – I may need to take smaller usage clients. |
| 6 | How much can I afford to give for it? | £X per month | On average, Xkwh per person – but if I build more plant, Ykwh |
| 7 | How much is the minimum that I need? | Enough to heat one radiator and one lamp | On average, cost price + £X – but I will support some "loss leaders" for loyalty in the future |
| 8 | Who can I get it from? – possible suppliers | Are there any suppliers of this product? | Potential customer base includes all homes on mains – could expand by instigating "new homes on mains" usage case. |

The reverse usage case has the following successful scenario:

The electricity supplier wants to sell electricity according to its requirements. The electricity supplier approaches a *potential customer* and offers to sell the *customer* electricity according to its requirements. The *customer* agrees to buy electricity from the electricity supplier according to his conditions. The *customer* pays for the electricity in accordance with the electricity supplier's requirements. The *electricity supplier* supplies the electricity in accordance with the *customer*'s conditions.

9.8 Step Six: Assembling the Evidence

The research that went into the case study resulted in a number of performance indicators being identified. These ranged from high-level "key" performance indicators (KPIs) such as the number of warnings or reprimands from regulatory bodies (such as SEPA – the Scottish

Scottish Environment Protection Agency; or the HSE). Information that is recorded at the tactical level included the number of hours that had been worked as overtime.

Some of these “measures” turned out to be difficult to relate to performance. For example, high levels of overtime might be an indicator of high levels of electricity generation, due to water being used to generate electricity throughout the night. On the other hand, if the overtime was due to unplanned maintenance, then this could indicate poor planning or execution of preventative maintenance.

One of the main difficulties in working in the hydro-electric sector is that key measures, such as efficiency, can be difficult to calculate because the exact amount of potential energy (e.g. water) going into the system can only be estimated.

Another key finding from this research is that organisations (not just SSE, but others with whom the author has worked recently) have a tendency to adopt measures that relate purely to “outputs” rather than service performance outcomes. This is partly because guidance on these issues, such as that given through the IIMM (IAM, 2002) tends to be somewhat “sketchy”. For example, a “measure” such as “number of planned schemes that have been started” does not really relate to performance. Instead, indicators relating to the efficiency and effectiveness with which the schemes have been constructed, might be a better link to performance as perceived by the various stakeholders.

9.9 Step Seven: Applying Value Functions

The case study revealed that perhaps the most useful value function was the s-shaped function. This is because it could be used in the many cases where there was some ‘soft’ step point at which performance began to drop off slowly. For example, a value of 80% might be considered to be 50% good (Score of 0.5), while a value of 85% might be very much better, and a score of 75%, very much worse. At the same time, once a performance indicator value of, say 90% was achieved; very little extra performance would be gained through increasing that value towards 100% (indeed it might not be cost-effective or best value for money). Similarly, once the value had fallen to, say 60%, the performance would be so bad that further deterioration would have almost no perceivable impact on performance.

In other cases, such a ‘soft’ step was not required. This would be the case where a particular performance indicator value results in a total ‘switch’ in performance. For example, a record

of zero deaths in one year would result in a score of 1.0 (best possible performance). but, since one death on site is unacceptable, a performance indicator value of 1 or more (which did not exist at SSE!) would result in a performance score of 0.0 for that PI.

Other performance indicator shapes can also be useful. For example, an organisation may feel that it is very important that safety inspections are carried out on time. Of course, an indicator such as “percentage of inspections carried out on time” is common, although it could be improved if the number of days was also considered (so that one or two inspections are not allowed to become overdue by many months). An indicator of “total days by which inspections were overdue” might be at least as useful. In this case, a concave Value Function with a negative gradient might be appropriate, so that performance falls away very quickly as the number of days by which inspections were overdue moves away from the optimum, zero.

9.10 Step Eight: Associating Evidence with the Diagram

The case study was of a simplified dam system, and as such the “evidence” that was used was not real. The example given in Figures 9.8 to 9.10 shows a large area where there is no evidence associated. This is because the option of using steam to drive a turbine was not considered. This could provide a further way in which the organisation could make use of the water stored in the system.

In a “live” project, this step can prove useful for identifying areas of the system that are not currently being monitored. This demonstrates the strength of the process-focused model, rather than a simple asset hierarchy, since it helps to ensure that all aspects of performance of an asset are considered.

9.11 Step Nine: Understanding and Reviewing

The case study model was essentially illustrative and did not contain actual data. As such, it was not suitable for carrying out scenario testing, benchmarking or gap analysis. However, in subsequent practical studies, these hoped-for benefits of the model building proved workable and useful. Examples can be found in Langman and Brown (2003); Langman and De Rosa (2003); and Langman, Roberts and Leicester (2003). More examples are due for publication in the near future.

9.12 Step Ten: Holding the Gains

This methodology supports all the needs of an enhanced asset management methodology, with the exception of providing predictions of future performance. However, what it does do is enable the organisation that have built the model to examine the effect that uncertain future behaviour can have on decision making. The approach supports Knowledge Management work by identifying individual process owners and illustrating areas where performance is not currently monitored. It is clear from the case study how an individual working at the operational (lower) part of the model can have an effect on the overall performance of the organisation; thus bridging the tactical gap.

Finally, because different value function shapes can be used for the same performance indicator(PI), a PI cascade can be developed that can enable benchmarking across a number of organisations within a sector. In this way a central authority (such as the Government) can set up a consistent framework of PIs that can be reported and measured across a sector (by a number of local authorities, for example). This can facilitate the sharing of data collection resources, using a consistent method, while enabling local priorities to be taken into account through the use of different value function shapes.

9.13 Conclusion

Since carrying out the original research at SSE, the author has been involved in a number of projects where the above methodology has been tested. Unlike Flood (1999), Kaplan and Norton (1996) and Rummler and Brache (1995), this approach provides some simple guidance in how to construct and test a process model.

The methodology begins with the vision and mission of an organisation. Where this is not clear (Senge, 1990) then it must be derived before the process model can be constructed. The strength of this approach is the clarity of the modelling guidance, and the way it integrates with existing Asset Management best practice to provide an enhanced approach to Asset Management planning.

The approach takes a good deal from the field of Value Engineering, but the “revised” grammar, described in Chapter 8, has proved more useful than the approach recommended in VE (Kardos, 1993). In addition, the use of the hierarchical model, rather than a network, with the driver of “How” acting downwards, “Why” upwards (and “When” across) is an advance on the loose network of FAST diagrams. The recognition that the children exist

because the parent requires them, and that the children sum up to *equal* the parent has been taken from the latest in systems thinking (Blockley and Godfrey, 2000) and is an advance on the VE approach.

The main weakness of this methodology is that ten steps are too many to remember. Therefore, during the months after the original case study was carried out, the ten steps have been reduced to the five-stage Performance Improvement Cycle (PIC) introduced in Chapters 8 and 9, and described in more detail in Appendix D.

Conclusions and Recommendations

10.1 Introduction

This thesis has described the current best practice in asset management within the dam sector, and shown how this could be improved through current best practice as described in recently published documents. Next, through a review of systems thinking in its broadest sense, including quality management and risk management, key mechanisms of thinking have been identified that could lead to an enhanced asset management methodology. This has been developed through the use of an illustrative case study example, described in the previous chapter.

This chapter aims to bring together the various strands of the thesis and demonstrate the way in which they represent a step forward in the asset management of engineering assets; which could be applied in the hydro-electric dam sector and elsewhere. The key areas of learning, which might be considered a contribution to the “Network of Knowledge” (Capra, 1996) are identified first, and a review is made as to whether or not these address the original objectives of the research, as presented in Chapter 1.

A summary of the key points of each chapter is given which demonstrates the way in which the thesis has developed, building, layer by layer, on existing thinking, to provide an iteration and synthesis that brings together the best thinking of today, to provide a step forward to better asset management decisions in the future. This does not pretend to be the “final” answer to asset management for complex infrastructure systems, but should provide a clear and coherent framework for future researchers to build upon.

Finally, this chapter draws the thesis to a close by suggesting areas where specific, academic, research could assist on continuing this journey towards the more efficient, effective, and sustainable management of physical infrastructure, with a full acceptance of its close association with “soft”, human systems.

10.2 Original Contributions to the Network of Knowledge

There are a number of simple, yet significant, ways in which this research contributes to the field of systems thinking for asset management. These are:

- An important iteration through systems thinking; bringing together current best practice in Asset Management, Quality Management, Risk Management, with existing models resulting in a simple process modelling methodology that builds on Value Engineering;
- A new language of nouns and verbs that drive improvement in the long-term, rather than “increasing for the sake of increasing”; and
- Tables for checking robustness of the model, through looking at the flow of demand and response through the system.

10.3 Review of Objectives

The progress made towards the original five research objectives, listed in Chapter 1, is given in the following sub-sections.

1 To identify the current challenges faced by infrastructure-intensive organisations and evaluate current Condition Monitoring and Asset Management methods

Through background reading and the elicitation methods described in Chapter 3, the current complexities of asset management in the hydro-electric dam sector were identified. A review of current best practice in that sector, and in asset management in general, revealed that there is a trend towards risk assessment as a basis on which to prioritise work. There are two key points that arise from this:

- 1) Successful risk assessment depends on a full understanding of the system in questions; and
- 2) Risk-based approaches tend to focus on negative consequences and may ignore the positive business benefits of intervention.

It became clear that a review of existing systems thinking was required in order to determine whether there were any methodologies that would overcome these two issues.

2. To identify and evaluate possible methods for modelling the performance of a complex infrastructure system and discuss critically some of the fundamental issues underlying current modelling ideas and techniques

The sixth chapter of this thesis brings together a review of systems thinking and describes some of the key existing models. However, it transpires that while there are many modelling ideas available, these are very much in the abstract. Guidance with regard to how to construct models is generally limited to particular techniques, particular risk assessment (Fault Tree Analysis, Event Tree Analysis etc), quality management and value management. This research has drawn on these existing ideas to produce a methodology that provides a more detailed description of how an infrastructure system (including “soft” interactions) can be modelled, such that the impact of operational, tactical and strategic decisions can be linked to overall services performance.

3. To identify and discuss critically the benefits and constraints associated with existing systems models, and select the preferred model type for this research

At the outset of this research it was thought that there might be some generic modelling methodology that could be adapted for the purposes of this research. At that time, the scope was to identify a model that would make the best use of the CMAM (now Perimeta) research. However, in the interim, the development of the International Infrastructure Maintenance Manual (IIMM: IAM, 2002) and the Asset Management PAS (BSI, 2002) led to the revelation that this methodology could provide a step forward towards an enhanced approach to Asset Management. At the same time, the new ISO 9001 standard and EFQM Business Excellence Model revealed that process-centred thinking was being seen as the way forward in ensuring quality delivery of services.

In essence, it has become clear that quality, risk and asset management are co-dependent processes. The aim of asset management is to minimise risk and maximise quality, whilst maintaining the required level of economic efficiency. This research has looked at modelling ideas in all these areas, and concluded that the optimum approach is to combine the best elements of each, to provide a better, more transparent, clear methodology for process modelling.

4. To produce a robust generic methodology for modelling a complex infrastructure system based on the outcome of objective three, and to carry out a case study of a major asset belonging to Scottish and Southern Energy plc and test the outcomes of objectives one through three

Without doubt, this research has met the aim of generating a generic methodology for modelling complex infrastructure systems. Following on from the original period of research, the methodology has been tested in a number of sectors, which has allowed the author to expand on the “soft” issues that must be considered when building process models. These include suggestions for facilitating workshops where the “power” balance might otherwise stifle creativity.

The case study with Scottish and Southern Energy plc was a catalyst for all the further research that has led to the enhanced methodology. It is not detailed, and there are certainly plenty of issues relating to the management of data and data quality that were not addressed during the original research. These are the subject of continuing consideration through projects with a number of infrastructure-based businesses throughout the UK, which should be published in the coming months. Nevertheless, the case study described in this work does meet the requirements of the original objective, resulting in the testing of the modelling methodology, which ultimately led onto the further improvements; the Performance Improvement Cycle, described in Appendix D.

5. *To evaluate the usefulness of the model methodology and comment on whether the tools chosen to construct the model (through objectives one to four) are viable or could be modified in some way, and provide generic suggestions for using this work to model and thus improve other complex asset management systems*

Chapter Ten contains an evaluation of the usefulness of the model methodology. It is clear that the approach does represent a step forward in holistic, systems-based asset management: bringing together the best of risk management, quality management and touching on knowledge management. It is not a “final” solution, and will, and should, be improved in the future. The dream that the methodology should provide a basis for practical work has been realised. The author is now leading a team at FaberMaunsell who are applying these ideas, through the Performance Improvement Cycle (a further iteration of the methodology described in Chapter 8) in “real” projects, across a number of sectors.

With regard to the tool used, Perimeta/CMAM has proven a powerful resource for modelling of this type. While software such as VISIO or Qmap are certainly sufficient for producing hierarchies or networks of processes, they do not have the advantage of being specifically designed to capture information about each process and, most importantly of all, do not enable the user to visualise the relationship between the performance of each child holon and that of its parent. The Perimeta/CMAM tools allow those looking at the model to carry out

rapid scenario testing and view the way in which evidence from lower level processes propagates up through the model to impact on the performance of the system as a whole. It is this aspect that enables the tool to support the generic methodology developed through this research.

A more detailed review of the methodology and the tool is provided in the following sections, with the practicalities of applying the approach to working companies (rather than just a theoretical case study) presented in Section 10.10.

10.4 Review of the Research Approach

The approach to the research, described in Chapter 3, was a mixture of traditional background reading, combined with best practice from the field of decision support. This approach was successful to an extent, although, if the author were to redo such a project, in the light of what she has learnt from this research, she would make some changes.

Since conducting the original research, the author has used the Solutions Focus as a methodology for encouraging the creative process required to build robust process models. This has proved successful, and may be the subject of future research and papers.

10.5 Review of Asset Management

The current state of the art of Asset Management brings together a number of useful tools, including risk management and quality management. The problem is that, in order for these to be successful, it is essential that there is a clear understanding of the system in question. Therefore, this research suggests that current best practice in Asset Management can be enhanced through a reliable approach to systems modelling.

10.6 Review of Systems Thinking

It is impossible to summarise the field of systems thinking as it is, by its very nature, without boundaries. A number of key models, such as Beer's Viable Systems Model and Checkland's soft systems models have been reviewed. It is clear that, while these may be conceptually elegant, they are limited in terms of providing a "recipe" for process modelling. The approaches of Rummler and Brache (1995), and the Balanced Scorecard of Kaplan and Norton (1996a/b), emphasise the need to identify links between processes within the system, but do not give practical measures for how this is done. However, as Deming tells us, there is no use in having management systems that are not transparent to those working within the

system. In the opinion of the author, this is why models such as the EFQM Business Excellence Model have limited use in the long-term; leading to attractive “poster” statements, rather than real changes. The approach developed through this methodology brings together “best practice” in order to develop visual systems models that enable people from throughout an organisation to see how their work contributes to the success of the systems as a whole.

10.7 Review of the Modelling Methodology

The methodology developed throughout the course of this research was originally intended for use in building models for the CMAM work, that would be robust enough to stand up to scrutiny and audit. It transpires that, through the review of asset management and existing systems thinking, this methodology may have a number of other benefits. CMAM stood for “Condition Monitoring and Asset Management”, but ultimately, this work has shown that “condition” is in fact just a subset of performance. In addition to “condition”, capacity, efficiency, cost and sustainability may be other key elements that should be considered.

Ultimately, without understanding how a system is performing, and determining which elements of the system are important, it is impossible for those managing assets to determine where money should be spent next. The aim of this approach is to develop models that not only allow the user to identify how the system is currently performing, but also to investigate uncertainties regarding how assets behave and react to intervention.

The ten-step methodology, described in this thesis, has a number of strengths:

1. The approach compliments existing methodologies, including risk assessments, quality management, the EFQM Business Excellence Model and the Balanced Scorecard;
2. The completed model provides a benchmark against which scenarios can be tested and improvements made;
3. The completed model is visually simple, yet complexity is captured and “hidden” as part of the modelling process;
4. A number of tools, including the IDEF family, the UML and the BCIOD+R acronym (Blockley and Godfrey, 2000) have been identified that stimulate the creative process;
5. A simple “grammar” stimulates robust model design;
6. Tables of demand and response act as method for checking the robustness of the model;

7. Unlike “Business Process Reengineering”, which was the buzzword of the 90’s, this approach enables people to see that the core processes will remain broadly the same in the future as now. Although the weightings may change, the “should be” and “as is” models will be similar structures, although the future model may contain more colour; evidence in the Figures of Merit. This is much simpler than the Kaplan and Norton (1996a/b) or Rummler and Brache (1995) approach which recommends building “as is” and “should be” models; and
8. The initial model will describe the current performance of the system in question; e.g. how good we are at *doing* what we do. This can be easily extended with a “reflective” model to provide a view of how good we are at *knowing* what we do. This can provide the foundation for knowledge management or linking the impact of data quality on service delivery.

The key strength of the approach is that it recommends starting by considering the mission or vision of the organisation and then building a “T-shape” model, with the “stalk” of the “T” focusing on a key function of the organisation before moving onto other areas of the business. This approach has the key advantage that problems, including lack of evidence, can be identified and acknowledged. This enables decision-makers to move away from what is essentially guessing, and towards a more holistic approach to planning. In this way it is possible to ensure that the system is optimised overall, rather than suboptimisation that can occur through localised, disconnected “improvements”.

10.8 Review of the Case Study Model

The model of Scottish and Southern Energy (SSE) developed as the centre of this case study is limited in several ways. The most important limitation is that it does not contain any data. This has partly been the choice of the author, because the incorporation of actual data might, due to commercial sensitivity, have resulted in restricted access to this thesis. This would have been a pity because, while the contribution of the author to the field of systemic thinking may not be revolutionary, many of the ideas, and in particular, the synthesis of current thinking, may be of interest to a wider audience.

The second reason why the model is limited is related to confidence: both that of SSE in the research programme; and, perhaps more importantly, confidence of the author in her own proficiency. In fact, the “fully-dressed” case study (Larman, 2002) might better be described as “naked” or “semi-clothed” containing as it does some, but not all, elements of the modelling methodology outlined in Chapter 8.

However, it must not be forgotten that the modelling methodology has been created as a result of the attempts to model part of SSE, rather than as a precursor to that work. Therefore, if the author were to repeat the project, the model would be much more complete. In a “real” situation (rather than academic research) the following key elements would have been set in place before the modelling process began. These elements, incorporated with “Step 0” of the proposed methodology, would include:

- Establishing organisational “buy-in” and support of the project;
- Carrying out a one-day inception workshop to ensure fit between organisation and methodology; and
- Bringing together a core High Performance Team (Blanchard *et al*, 1992).

The comment regarding organisational “buy-in” is in no way a criticism of SSE. The members of staff who were consulted throughout the research were interested in the project and went out of their way to support the work; including attending the CMAM project seminars held at the University of Bristol. Rather, the failure to fully establish organisational “buy-in” resulted from the fact that the methodology for doing so had not yet been identified by the author. Indeed, it is only in recent months that the author has been able to clearly describe a “product” or “service” that an organisation can buy into. This is the Performance Improvement Cycle, developed with the support of colleagues at FaberMaunsell and through recent projects, which is presented in Appendix D.

The original workshops that formed part of the CMAM project were not specifically aimed at establishing a “fit” between the research and the organisation, as SSE had already demonstrated their commitment through providing financial support. In addition, the methodology had yet to be developed, so it was impossible to ensure that it was appropriate for the organisation, since it only existed in the “fuzzy” mental models (Senge, 1990) of the CMAM research team.

While it is likely that SSE, being one of the leaders in their field, would have been open to the concept of forming a Higher Performance Team for process improvement through constructing a process model, the author did not have the knowledge and skills at her disposal to facilitate this until later on in her research. Therefore, the author created the model with contributions along the way from the CMAM project team. It should be noted that the process of building the model has been refined throughout the research and the models presented in the original papers (e.g. Hall *et al*, 2001) have since been refined as a result of the deeper understanding of systemic thinking that the author has gained through

the course of the research and subsequently applying the ideas in the commercial environment.

It is fair to say that the process model presented in the previous chapter is as robust and complete as it could be in light of the situation described above. Most importantly, it has fulfilled the key function, which has been to provide an environment in which the researcher could develop and refine her modelling ideas. In particular, the process of building the model has enabled the author to extend the existing understanding of the process of building a robust and defensible process model; which comprises part of the original contribution (see above) that this work makes to the Network of Knowledge (Capra, 1996).

10.9 Critique of the CMAM Modelling Tool

The CMAM (now Perimeta) methodology has a number of key advantages. One of the main strengths is the fact that the diagrams that can be produced with it are visually simple, yet the tool enables the user to capture complexity in a hidden format. In addition, the ability to view different aspects, such as safety, cost, or the Environment, is an added advantage of the tool. Small details, such as the grid for lining up holons, which toggles on and off, are also useful, as is the reporting function in the Perimeta version of the software.

The new version of the software, Perimeta version 1.0, has two methods for propagating evidence. The original version, CMAM, which uses interval probability theory, is described in Hall *et al* (2002a), while the Juniper algorithm propagates the red and green separately. The advantage of having these different types of propagation is described below.

There are, however, a number of problems that still exist with the Perimeta tool. These are as follows:

- The original method of drawing a value function, by stating maximum and minimum values and curvature meant that the values of 1 and 0 are not always reached. Additional value functions (for example, allowing the user to specify the midpoint) are an improvement, but some functions can still not be modelled appropriately;
- There is, as yet, no space within the system for viewing time series. Thus, the user must ensure that this is done in the database from which the data is drawn;
- Where a Performance Indicator should lie between two values (e.g. in a flight envelope) this has to be modelled as two performance indicators, with a separate value function for “high” and “low” values. This leads to conflicting

evidence. This problem can be sidestepped by recording the absolute value of deviation from the mean, but a flight envelope approach should still be considered in the future;

- The methodology is not appropriate for real-time recording of performance if the flight envelope (performance criteria) are likely to change frequently, as this would involve repeatedly updating the value function shapes;
- The tool allows the user to record information in freetext spaces but does not request particular items of information. Individual user organisations might wish to add prompts to the system to ensure that key information (such as process indicators, names of team members who determined the value function, etc) are recorded for posterity;
- There is no clear audit trail – entries and changes should perhaps be time-stamped and attributed to a particular author or editor;
- The methodology could benefit from being linked to an approach, such as Statistical Process Control, which allows the user to check whether the values being given for good and poor performance are meaningful, in terms of statistical probability;
- The upward facing arrow in Perimeta is supposed to show the flow of evidence. In former versions of the software, downward arrows were used to show that the parent holon “is made up of” the children. The upward arrow merely results in a small black triangle at the bottom of all but the lowest level of holons (the arrow head);
- There are some areas where the visual display could be improved, providing much more value to the user. For example, although all performance indicators (PIs) associated with a process result in a combined Figure of Merit (FoM) for that process, there is no way of seeing (graphically) how each PI is contributing to that combined FoM. Perhaps the individual FoM for each PI could be shown separately, on a tab in the holon information panel, and/or all the PIs making up an FoM in the process model view could be revealed or hidden as required;
- The tool might benefit from more warning systems. A yellow triangle is shown next to a holon if evidence local to that holon is used. Similarly, it might be appropriate to have a warning shown on the “aspect” views of performance (e.g. safety, environment, etc.) if value function is amended in that view; and
- Finally, the use of text-wrapping in the freetext boxes in the information panels would make this much easier to read.

The new version of Perimeta now has three propagation options:

1. Suspend propagation;
2. Juniper (weighted red/green) propagation; and
3. CMAM (Interval Probability Theory) propagation.

The author has found that all three of these propagation methods are required in order to “see the truth” of the problem. Three examples of use are given in Figures 10.1 to 10.3. In each example, three children are associated with the parent. Initially, the first child is known to be completely succeeding; the third is completely failing. The performance of the middle child is completely unknown. On a copy of the diagram, the performance of this child is assumed to be complete failure, and the effect that this has on the parent is shown.

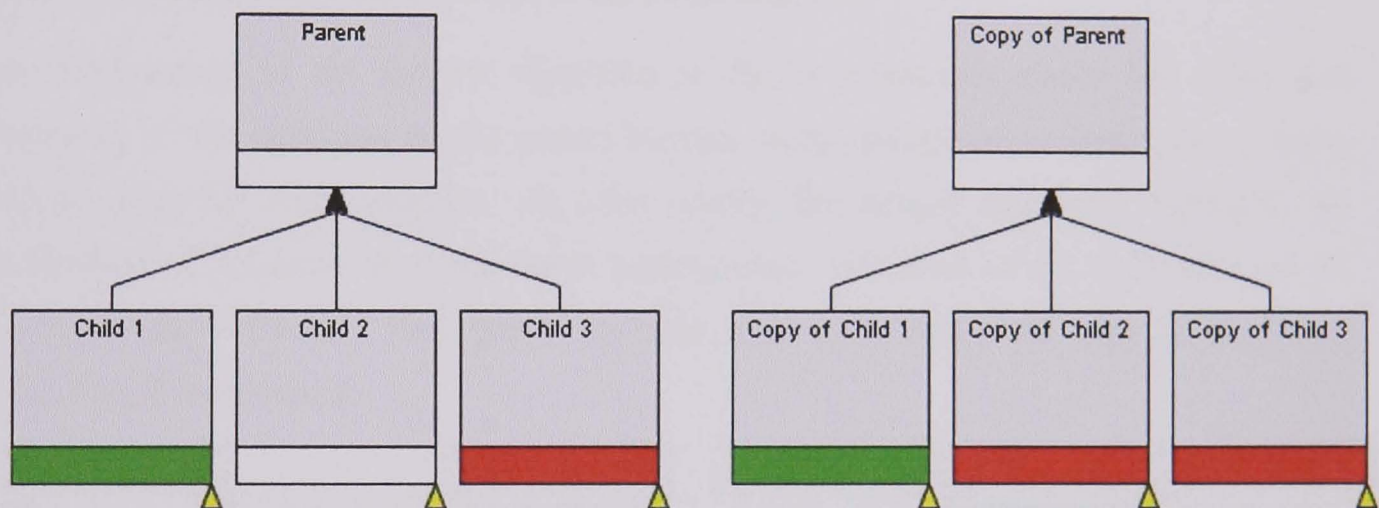


Figure 10.1: No propagation

When no propagation takes place, no evidence is passed up to the parent. This might seem a meaningless exercise as first, but it is very useful when the user wishes to gain an objective understanding of those areas of the system where performance is currently being measured directly and what that locally measured evidence is showing. Once propagation takes place the areas where local evidence is supplied can still be identified by the presence of yellow triangles, but the local contribution of that evidence is masked by the propagation of other evidence (which may be weighted the same, more or less than the local evidence).

The Juniper algorithm (Davis and Hall, 1998) is based on a simple weighting of evidence for (green) and against (red) the success of a process. The sufficiency value (S) applies to the green, and the necessity (N) to the red. This has the advantage that the results gained are intuitive. In the example in Figure 10.2, since $S=0.4$ (for Child 1), 40% of the green is propagated, as is 40% of the red (from Child 3). When the second child is shown to be

failing this has the intuitive effect of increasing the red of the parent. In fact, the red and green cross over, which shows that the evidence of the children is conflicting.

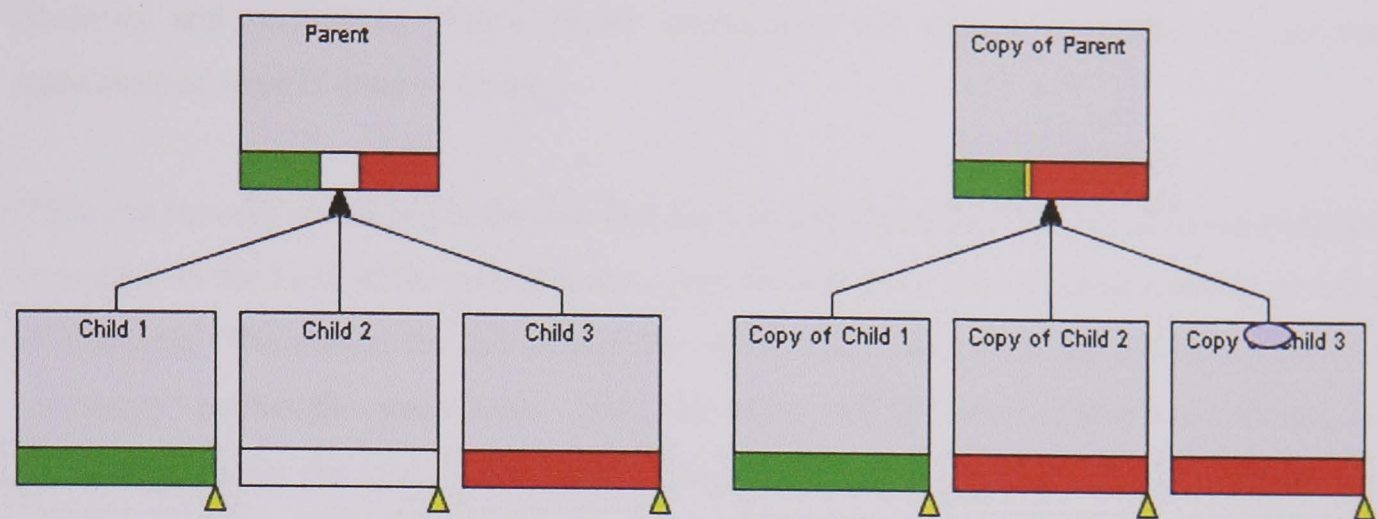


Figure 10.2: Juniper Algorithm ($N=0.4$; $S=0.4$ for all children)

The disadvantage of the Juniper algorithm is that it sometimes masks the effect that uncertainty in the child has on the parent because of the weight of evidence that is being propagated up by other children. In other words, the Juniper algorithm highlights the contribution of *evidence* to higher-level performance. Because of the symmetry of the problem given, if Child 2 were green, the ratio of green to red in the copy of the parent would simply be reversed.

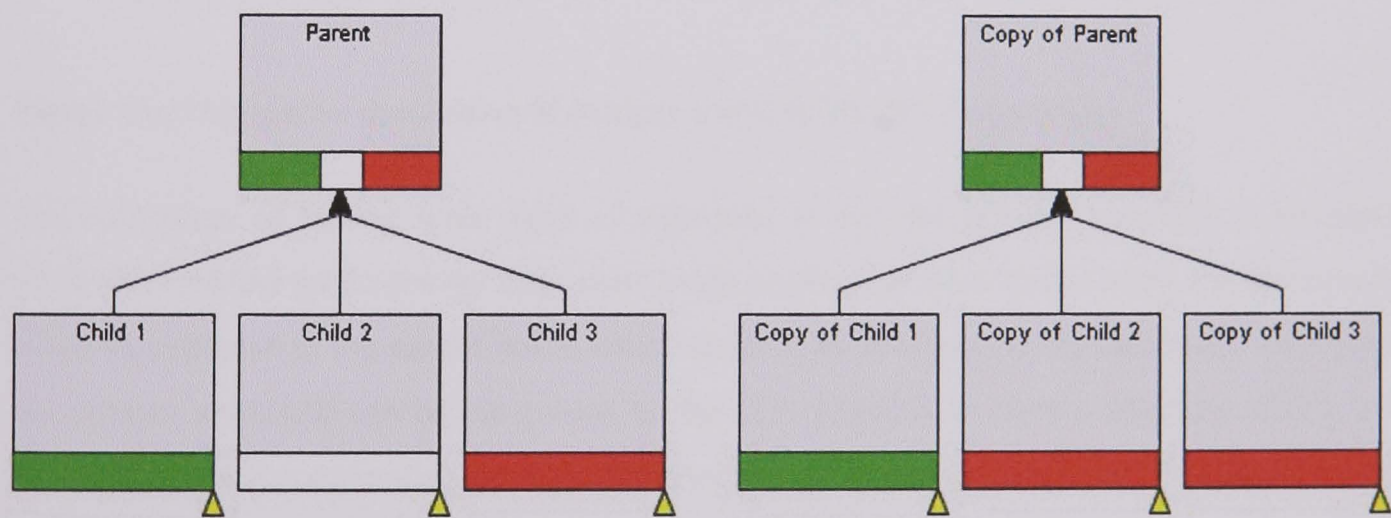


Figure 10.3: CMAM Algorithm ($N=0.4$; $S=0.4$ for all children)

The Interval Probability Theory (IPT) approach was the original basis for the CMAM methodology. It aimed to overcome arguments that the Juniper “weighted” approach was not mathematically robust, since, in some instances, it could mask uncertainty (Hall *et al*, 1998, 2000, 2001, 2002 a/b, 2003). However, the IPT approach is not so intuitive. For example, in Figure 10.3, adding extra “red” through Child 2 does not result in any change in the parent. The reason for this is that the CMAM methodology “recognises” conflicting

evidence, and, instead of propagating the green and red separately (which allows them to cross) takes the two points that form the white and works with these. Therefore, because the necessity and sufficiency values remain unchanged, the amount of white will not vary regardless of what is done to Child 2.

What can be very confusing is the fact that the CMAM algorithms can result in red and green appearing in the FoM of the parent holon, even though there is no evidence shown in any of its children. The reason for this is that the “sufficiency” will push the red back, while the “necessity” pushes the green back. Thus, the white will fall between these two values, and red and green fill the space either side. Thus, the CMAM approach can be thought of as highlighting the contribution of *uncertainty* to the performance of the parent.

The difference between the Juniper and CMAM algorithms is described figuratively in Figure 10.4.

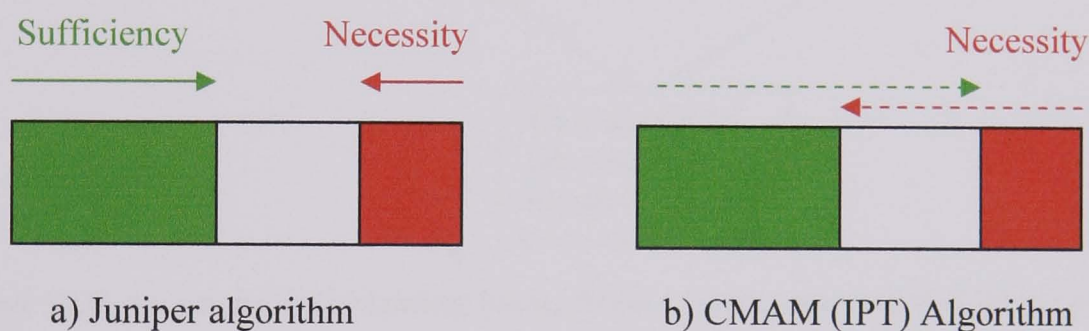


Figure 10.4: Figurative description of Juniper and CMAM (IPT) Algorithms

The advantage of having both types of algorithm is that the Juniper approach is intuitive, while the CMAM methodology can create some results that on initial viewing appear strange (such as evidence in the parent holon where there is no evidence in the children). However, the Juniper approach can be dangerous in that it is possible to have a situation where, say two children are contributing enough evidence to “fill” the parent’s FoM, but a third child, with no evidence has higher sufficiency and/or necessity. Unless the user is careful to check what might happen if evidence were added to the third child they might be left with the misapprehension that the performance of the parent is known, when, in fact, the performance could be dramatically altered by additional evidence in the third (or more) child. The CMAM methodology overcomes this by limiting the evidence fed up by the other two processes because the necessity and sufficiency values of the third process are larger.

Thus, it has become clear throughout the course of this research and subsequent work, that both propagation approaches, and the zero propagation scenario are useful.

The idea of connectivity is one that creates some practical difficulties. While in reality it is clear that processes are multiconnected this can be very difficult to represent in practice. Even when systems thinking is used to develop Knowledge Management systems (Marchand *et al*, 2000) it quickly becomes very complicated if every link is shown. After much debate it was decided in both the Juniper and CMAM projects that multi-connectivity should be possible as it is practically desirable. However, while there is an obvious demand for this, it does provide a conceptual difficulty, which the author has grappled with throughout the course of this research. That is, if a set of child holons “adds up” to the same as the parent holon above (Blockley and Godfrey, 2000) then how can one child process contribute to two parent holons? An example should illustrate the nature of the problem (Figure 10.5).

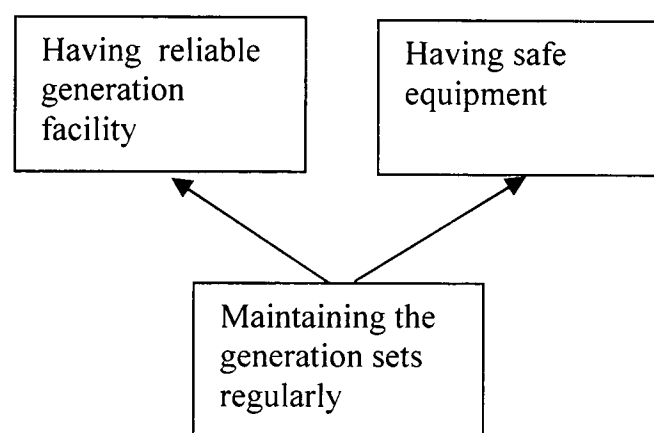


Figure 10.5: An example illustrating the problem of multi-connected child processes

In the author’s view, a hierarchical model with multiconnectivity between child process that “belong” to different parents can quickly cause confusion and reduce the usefulness of the model. Therefore, it is recommended that two similar child holons should be devised. In the example above these might be “Maintaining the generation sets for reliability” and “Maintaining the safety of the generation sets”. It has frequently been the case that this has revealed a need for meaningful performance indicators that would never otherwise have been identified until a problem occurred.

10.10 Applying the Methodology to a Working Company

The key issues to bear in mind when transferring this methodology to a working company will be those highlighted in the first two steps and the last step of the proposed enhanced asset management methodology. Both of these are to do with eliminating fear and overcoming inertia.

Since carrying out the research for this thesis the author has been developing the ideas in the water, rail, highways and property sectors. She has found that it has been a real challenge to promote these ideas within industry. The main reason for this is related to the difficulty in communicating and demonstrating quantifiable benefits.

Step Zero of the methodology (Preparation) is essential for ensuring that the methodology is being applied in a way that will help the organisation. For example, in the highways sector there is a current focus on performance indicators, prescribed by central government, that are meant to be driving Best Value (thus referred to as BVPIs). However, most local authorities are finding that this is resulting in a good deal of work, collecting, analysing and displaying information that does not ultimately inform local decisions. Thus, by understanding these issues, the Performance Improvement Cycle was developed to help authorities demonstrate to the Audit Commission their reasons for prioritising some BVPIs over others; to reflect local needs.

Similarly, the water industry is heavily regulated by Ofwat and the DWI (Drinking Water Inspectorate). Companies are required to complete Periodic Reviews (PRs) every five years, to justify investment decisions. The amount of uncertainty relating to the current state of the assets (which are frequently poorly recorded and hidden) as well as to their future deterioration, has meant that the approach described in this document has given organisations a framework against which to plan and defend their spending decisions.

Another area where there is a need to demonstrate performance is in the rail sector. Work with one train operating company (TOC) focused on how changes at the operational level, in terms of maintenance regimes for example, could impact upon the customer experience. A similar approach could also be applied by the ROSCOs (Rolling Stock operating Companies) and Network Rail, perhaps ultimately resulting in a model of the performance of that industry as a whole.

Once the client issues have been thoroughly researched and the client is approached with the project it is necessary to lay the foundations. Like the preparation stage, this has been developed through marketing attempts following on from the original research. The important thing to remember that it is essential to be able to “draw a picture” of what the client is being asked to buy into. In particular it is useful to be able to make clear what the service is and what the tangible benefits may be for the client. At present the author is undertaking work with a number of organisations with the aim of helping them use the approach to review the performance indicators and thus data collection work and databases

that are contributing most to their understanding of their business. Although it is felt that all staff should be retained, there work will be focused more efficiently, and tangible savings should be made through linking key data storage systems and discontinuing historical systems that no longer inform decision-making. Hence, it should soon be possible to carry out a cost-benefit analysis of the approach developed through this research.

With regard to the long-term benefits of this approach; it can provide a basis for Knowledge Management work (since each process has a prescribed owner), Enterprise Resource Planning (since the resources required for each process can be attributed within the process model), performance reviews (demonstrating how individuals contribute to higher-level aims) and as a communication tool; overcoming the tactical gap found in most organisations.

The approach used by the IAM in the International Infrastructure Management Manual (2002) is to divide the organisation into (roughly) three levels according to the length of time over which they are recorded to plan. Thus, the terms “Strategic”, “Tactical” and “Operational” are used. Recent experience using these terms in real life project reveals that they are terms that are complimentary and accepted by client groups in public and private organisations alike and that there is indeed a “gap” at the tactical planning level. Strategic plans are often clear (although the Vision and Mission are seldom well-communicated) and the Operational work continues along historic lines, with maintenance patterns fixed by habit rather than performance requirements. Although people at all levels are “doing their best” the lack of a tactical level of planning means that thinking is not joined up and local attempts at optimisation frequently result, as Deming predicted (Scherkenbach, 1991; Deming, 1986, 1994) in failure to deliver the required outcome. The enhanced asset management approach described in this thesis can draw these levels together, resulting in effort being expended in the right place in order to optimise the overall performance of the system.

10.11 Assimilation and Take-Up Issues

There are a number of issues that affect the take-up of this work by industry. The first of these is the fact that many organisations have been “stung” by expensive projects through the Business Reengineering, Balanced Scorecard and Business Excellence Models of recent years. They are loath to bring on board what they may see as another “buzz” word methodology. Therefore, it is essential that studies be undertaken into the cost/benefit of this work in economic terms. The author is confident that the enhanced methodology described in this thesis can help to ensure this is the case. In addition, this approach is entirely complimentary with work that organisations have already undertaken with regard to process-

modelling, risk analysis or performance and quality management. What this methodology delivers is an improved understanding of how these elements can be brought together and, through the Perimeta tool, a visual “picture” of what each of these are telling an organisation about its current performance and priorities for improvement.

The sufficiency and necessity terms can be quite difficult to explain to a non-mathematical audience, and must be presented in such a way that they are not a stumbling block for people wishing to use the methodology. In particular, the two different methods of propagating information (Juniper and CMAM) can appear to be conflicting, which can lead to confusion. The way to overcome this is to use an experienced facilitator with an understanding of the mathematics and principles of both approaches. However, it is essential that this understanding is shared with the group, otherwise the Perimeta tool will go the way of Value Engineering and the Balanced Scorecard; an expensive methodology that is delivered mysteriously by “wizards” with multi-coloured belts.

Many of the organisations for whom this methodology could be of greatest benefit are working with very small budgets, due to society’s failure to recognise the fact that physical assets such as bridges, pipes, buildings and so on, do have a finite life and require investment to slow deterioration. Thus, it is important that this approach is felt to provide value for money. In this climate where performance-based engineering is relatively new, it will be those people who demonstrate the greatest practical benefits in terms of delivering services more efficiently and effectively, that will be most successful.

The approach is generic and can be applied not only within engineering sectors, but also to areas such as education, social services and other “soft” services. Thus the approach could be used to demonstrate the global performance of a council, a county, a country; and demonstrate the impact that spending in each area will have on the performance of that organisation as a whole.

10.12 Further Areas for Research

Deming talks about the Voice of a Process and the Voice of the Customer (VOP and VOC). It is clear that this methodology provides a method for translating performance of a process in relation to the values of the customer (through the value function) but this is generally done in a “freeze frame” fashion. In other words, the value functions, if not the PIs themselves, would only be revisited periodically (say annually for most, monthly for a few). In reality, of course, the VOC is not necessarily constant. There is therefore scope for

further research into how real-time modelling could be carried out. The technology exists (e.g. PDAs and tablet PCs) to collect performance information and relay it almost instantly to a database, but the area that requires more research is determining which PIs require such treatment.

In this work, the area of control theory has been touched upon, but there is probably room for more research into how this can be brought more formally into asset management, through the use of a “flight envelope” idea. The performance envelope could have many levels such as Statistical Control Limits, Serviceability Limits and Ultimate Limit. In Figure 10.6 the area shaded in one direction has “failed” the first performance envelope/bounds at t_1 and then fails the second one at t_2 . Could action at time t_1 have prevented this? Obviously this is not a total structural failure because the indicator returns within acceptable bounds, however the asset may fail on another performance indicator. For example, when after an earthquake a building may be structurally sound it might be knocked down because it cannot be made habitable again.

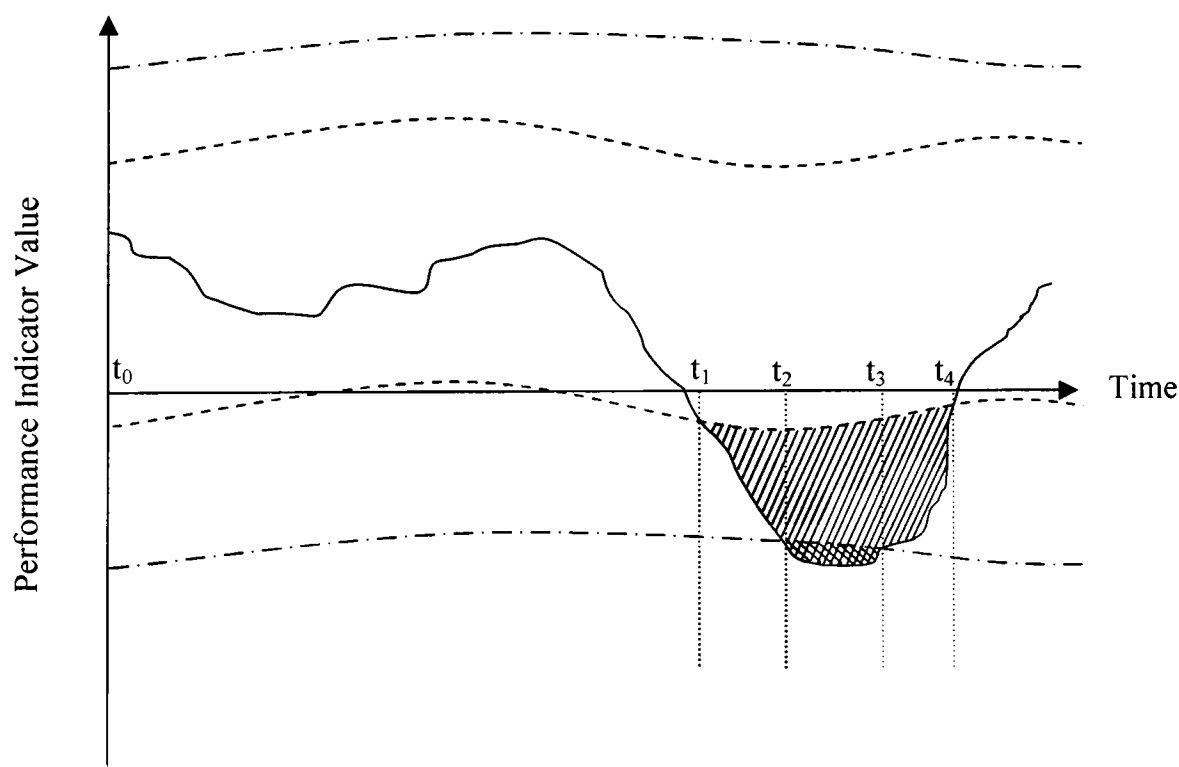


Figure 10.6: A dynamic flight envelope with variable Serviceability and Ultimate Limits

More work is also required on studying the way in which the ideas of sufficiency and necessity are explained to those people who are not interested, or are unable, to understand the mathematical equations; this might require some research in the fields of social science and psychology. In particular, the tendency, observed by the author, for experts to initially overestimate their knowledge and confidence in their opinion, before reducing this upon considering more objective methods of measuring performance, requires further research. There are doubtless a number of studies that have been undertaken into the way in which

people estimate risk that could be brought into play to make this approach still more robust. In addition, further research is required into understanding and communicating the meaning of dependency between different performance indicators and processes.

It is clear from reading the most recent literature relating to asset management (such as the IIMM; IAM, 2002) that there is a real need to be able to forecast performance.

“[Forecasting is essential for giving organisations the ability to] quickly and accurately align and realign resources with corporate strategies....business is starting to awaken to the growing need for corporate performance management (CPM), both from a process standpoint as well as a technology perspective....Integral to CPM success is a robust approach to forecasting. Forecasts – both revenue and cost – are the starting point for managing expectations both internal and external to the organization.”

(Comshare, 2002a).

In actual fact, what is required is more than the ability to forecast revenue and cost, as this is seen from the standpoint of an essentially static system. In this complex, dynamic world in which we find ourselves, where behaviour is non-linear, the ability to forecast performance will separate the best from their competitors. Further research is required to identify whether approaches such as Statistical Process Control (SPC) can be linked with the methodology described here in order to provide a better understanding of historical trends; thus leading to a stronger justification for forecasts. At the same time, there is a need for industry to pay more attention to those ideas that are coming from those like Goldratt who are considered as eccentrics. Their ideas, particularly in relation to uncertainty in project planning, could further widen the benefits from an approach of this type.

While the VOC has been interpreted fairly well through the value functions, this must be linked more formerly to market research and consultation. In addition, the VOP must be considered in a more formal manner through control charts.

Finally, there must be work carried out into bringing the “best of breed” approaches together. While the market operates from the point of view of competition and market domination, this may not be possible, but increasingly there are signs of companies working together to provide better value, packaged services to clients.

10.13 Summary of Findings

During the course of the research it soon became clear that a framework for supporting decisions was required for two reasons. The first of these is that when two or more experts are working together to make a decision there may often be a conflict of opinion (usually fuelled by incomplete knowledge by some or all parties). Techniques, described in Chapter 3, such as Repertory Grid Analysis and the Solutions Focus, Goldratt's Thinking Processes or the "Italian Flag" can assist experts in coming to an agreement even where it initially appears that a shared view can never be reached.

The second reason for the necessity of a decision-making framework is that, even when one expert is able to make the decision alone, there is a need for transparency. In this way, if the decision is ever called into question at a later date, the expert can justify their actions through reference to the record maintained in the framework. Similarly, in line with the principles of knowledge management, should a similar decision ever have to be made in the future (perhaps after that expert has left the organisation), the record of the original decision can be used as a template. In this way, the process of Continuous Improvement (Deming, various) and the concept of the Learning Organisation (Senge, 1990; Senge *et al.*, 1994) can become a reality. In the words of Senge (1990) it will then be possible to create:

A "learning organization" – an organization that is continually expanding its capacity to create its future".

(Senge, 1990)

Such an achievement would surely 'delight' (Blockley *et al.*, 2000) customers and shareholders alike.

There is a new "buzz" word emerging; "Business Intelligence" (Smith, 2002; White, 2003).

"BI [Business Intelligence] and business process management technologies are converging to create value beyond the sum of their parts"

(Mark Smith, 2002)

The methodology described in this thesis is an iteration along the road to bringing together different areas of work, from value management, risk management, asset management, financial management, performance management and other areas, to provide true Business Intelligence. The result of this work is a methodology for benchmarking current performance and prioritising work to improve knowledge and delivery.

The visual format of Perimeta provides a step-advance over more textual approaches that are merely signified by schematics (e.g. the Balanced Scorecard, the Business Excellence Model, the ISO 9001 quality circle etc.). However, more research is required into improving the ability to forecast future performance through better use of historical trend information. It is likely that the answer to this, as with many of the dilemmas of business in the last few decades, will lie in the work of W.E.Deming.

It is hoped that the current success of the methodology described in this thesis (as taken up through the Performance Improvement Cycle, described in Appendix D) and its compatibility with techniques such as the Balanced Scorecard, Six Sigma and the EFQM's Business Excellence Model, will see it playing an increasingly important role in ensuring the successful performance of customer-focused organisations in both the public and private sectors. If this approach can achieve this, it will have resulted in much more than the original aim of developing guidance for building process models, and will instead become a "hub" to which organisations can attach the "spokes" of relevant tools and methodologies as they appear in the future.

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Appendix A

Popular Business Modelling Tools

A.1 Introduction

This appendix contains a list of process modelling tools that were available on the Internet in 2001. It was compiled by a student at Delft University, Bart-Jan Hommes, investigating Business Process Modelling Tools. It was last updated on 20th June, 2001, so it is reasonable to assume that there are now many more models available. The list can be seen at <http://is.twi.tudelft.nl/~hommes/toolhits.html> and the tools are listed in what Hommes considers to be their level of popularity. There are 388 listed (number of “hits” in brackets).

A.2 The List

5 Internet sources

ARIS (12356)

Ithink (31564)

4 Internet sources

Extend BPR (1235)

First STEP (3156)

GRADE (2315)

Optima (3561)

Process Charter (2351)

Re Think (3561)

SIMPROCESS (2561)

Work Flow Analyzer (4651)

3 Internet sources

BONAPART (231)

BPWin (127)

Clear Process (356)

Designer2000 (157)

INCOME (216)

Object Maker (357)

Pro Vision Workbench (761)

Process Model (261)

Vensim (361)

Visio (125)

Work Party (241)

Workflow Analyzer (356)

2 Internet sources

APACHE (23)

Business Improvement Facility (23)

CADDIE (23)

Corporate Modeler (15)

COSA (15)

Form Flow (41)

Group Systems (21)

Group Wise (14)

In Concert (14)

Meta Edit (57)

Meta Edit Method Workbench (57)

METIS (31)

Micro SAINT (26)

| | |
|---|--|
| Office.IQ (41) | Applying Benchmarking (2) |
| OPENworkflow (41) | ATIWorkflow Manager (2) |
| Optima Express (35) | Automated Work Distributor AWD (1) |
| Powersim (61) | AWD and Workflow Analyzer (1) |
| Pro CAP Pro SIM (25) | Bachman Analyst (2) |
| Pro Model 2.0 (25) | BDF amp Power Gr AF (4) |
| Process IT (24) | Bench Marker Plus (4) |
| Process Weaver (21) | Best Practice Database (2) |
| Process Wise Workbench (12) | Beyond Mail (4) |
| RDD-100 (27) | BIS Process Manager (2) |
| Regatta (41) | BPM (1) |
| SA/BPR Professional (17) | BPSimulator Template (4) |
| SES/Workbench (25) | Bridge Point Automation Tools (7) |
| Staffware (41) | BRWin A&D (7) |
| System Architect (71) | Business Design Facility (3) |
| Taylor II (16) | Business Frame Work (1) |
| Team WARE (14) | Business Insight (2) |
| Win Work (41) | Business Object Modelling Workbench (5) |
| Workflow.BPR (31) | Business Process Analyzer (4) |
| WORKlogik TM (14) | Business Process Benchmarking Solution (2) |
| <i>1 Internet source</i> | Business Process Modeler (1) |
| 1View Workflow (1) | Bwise Toolkit (1) |
| 4Keeps (7) | CABRE -Witness (2) |
| ABC Flow Charter 4.0 (2) | Cap Web-Flow (1) |
| ABC Graphics Suite (2) | Case Wise (2) |
| ABSI-Docs (4) | Cinderella SDL (7) |
| ABT Project Workbench (2) | Class Designer (7) |
| Action Request System (4) | CLEAR (1) |
| Action Workflow Analyst (4) | CMSWorkflow (4) |
| Action Workflow Application Builder (4) | COI-Business Flow (1) |
| Action Workflow Enterprise Series (1) | Computer Based Training (2) |
| Action Workflow Workflow Manager (4) | Computron Workflow (1) |
| Activity Modeler (5) | COOL (1) |
| ADONIS (3) | COOLBiz (7) |
| AI0 WIN (5) | COOLJex (7) |
| all CLEAR (5) | |

| | |
|---------------------------------------|------------------------------------|
| COOLPlex formerly Synon Obsydian (7) | ETQ 9000Maps (2) |
| COOLTeam Work (7) | Excalibur EFSOE Electronic Filing |
| CORE (7) | Software (4) |
| Cosmo (3) | Expert Choice (2) |
| Cosmo IDEF Modeling Software (3) | F3 Forms Automation System (4) |
| COSY (1) | Fabasoft Components (1) |
| CRCPatterns (7) | File Net Work Flow (2) |
| Cross Approach (1) | File Power (4) |
| CSEWorkflow 5.0 (1) | Flo Ware (1) |
| Design CPN (2) | Flow Maker (4) |
| Design IDEF (2) | Flow Man (1) |
| Design Leverage (2) | Flow Path (2) |
| DOC-FLOW (4) | Flow PATH IMAGEWorks (4) |
| Docu Flow (4) | FLOWBuilder (1) |
| Document Manager (4) | Flowcharter (1) |
| Documentrix Workmanager (1) | Flowmark (1) |
| DPA (3) | FORO (1) |
| DPL (2) | Framework (6) |
| Dress Rehearsal (1) | Free Flow (7) |
| Dyna Metrics (6) | FYI (1) |
| Easy ABCPlus (2) | FYI Workflow (4) |
| Easy ABCQuick (2) | GD Pro (7) |
| Easy CASE Professionalfor Windows (7) | GOOFEE Diagrammer (7) |
| Easy EREasy Object (7) | Graphical Designer GDPro (7) |
| EDI36 (4) | Graphics Toll (2) |
| EDI38 (4) | Group Decision Support Systems (2) |
| EDI400 (4) | Group Systems Survey (2) |
| EDle QMail (4) | Group Wise 4.1 formerly Office (4) |
| ELF Legal Services (4) | Groupsystems (1) |
| Engineer (7) | HICOS (1) |
| Engineering Workflow System (4) | HITSoft BIZ (1) |
| Ensemble (1) | HOCUS (2) |
| Enterprise Analyst (1) | HOOD (7) |
| Enterprise Modeller (5) | Hood NICE (7) |
| Entire Workflow (1) | HOW (7) |
| EPIC (4) | i-think (4) |
| ERwin (7) | IBIsys (4) |

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| IBMBusiness Process Modeler (5) | Logic Works BPwin (3) |
| IBS Workflow Manager (4) | Logic Works OOwin (3) |
| ICONIXOOAamp D Power Tools (7) | LOREx2 for Java (7) |
| IDEF Tools (1) | Mac Aamp D (7) |
| IEW Planning Workstation (2) | Maestro II 4.0 (1) |
| Image Fast (4) | Magic Draw UML (7) |
| Image Master (4) | Manual Master (1) |
| Inform 1.0b (4) | MAVIM 3 (1) |
| Ingenium (2) | MAXIM (4) |
| Innovator (7) | Meetingkitsfor windows (2) |
| Intelligent OOA I-OOA (7) | Memo (4) |
| Inter Office (1) | Mesa CTI (7) |
| Intra O (1) | Message Driven processor MDp (1) |
| is Modeler (6) | Meta Edit Personal (5) |
| ISO Flow-Pro II (2) | Metaphase 2.0 (4) |
| Isosoft (1) | Metaview FOLDERS (4) |
| ISOxpert Managers Edition (2) | METEOR (1) |
| j-vision (7) | Micro Mentor Tools of Quality (2) |
| Javision (7) | MKS-intellect (1) |
| Jet Form Server (1) | Model-systeem (1) |
| Kaisha Modeler Pro (6) | Modeler Business Process Simulator (6) |
| Kameleon (6) | Moo D (3) |
| Kappa (4) | Mosaik (2) |
| Key Workgroup (1) | Movix (1) |
| Keyfile 2.2 (4) | Navigator 2000Document Management |
| Keyflow (1) | Systems Navigato (4) |
| Knowledge Ware IEW (2) | Navigator 2000Workflow (1) |
| LBMSProject Process Engineer (2) | Net Prophet (1) |
| LBMSSystems Engineer (2) | Nova Manage (1) |
| Learnfirst Benchmarking (2) | CTAVe Process Manager (3) |
| Learnfirst howto implement ISO 9000 (2) | Objec Time Developer (7) |
| Life FLOW (1) | Object GEODE (7) |
| Link Works Team Links (4) | Object Management Workbench OMWtm |
| Linkworks (1) | (4) |
| Live Analyst (5) | Object Modeler (7) |
| Live Model (1) | Object Partner (7) |
| l ivelink Intranet (1) | Object Plant (7) |

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| Object Team (7) | Process Builder (5) |
| Object Technology Resources BRAt | Process Flo (4) |
| Taligent R (4) | Process Guide (6) |
| Objecteering (7) | Process Maker (5) |
| Obsyidian (7) | Project Kickstart for Windows (2) |
| OCTO9000 (1) | Project Scheduler7 (2) |
| OCTOFlow (1) | Prophecy (5) |
| ODMS (4) | PROPLAN (3) |
| OFIS (1) | PROSIM Process Modeling Software (4) |
| OODesigner (7) | Protos (1) |
| Open Image (1) | Pyravision (1) |
| Optix Workflow (4) | Q (2) |
| Oracle Designer (7) | QFD Capture (2) |
| Oracle Process Manager (2) | QFD Designer (2) |
| OrgDesigner (0) | QMAP (2) |
| PACF (?) | Quality Improvement Tool (1) |
| Paradigm Plus (7) | Quality Links (1) |
| PAVONE Group Flow (1) | Quality Online (1) |
| Performance Mentor (2) | Quick CRC (7) |
| Performance Now (2) | radica (4) |
| PFTamptrade (1) | RADitor (2) |
| Phoenix GEM (3) | Re-Map (3) |
| Playground (7) | Real-time Studio (7) |
| pleasnote (3) | Revelation HR (2) |
| Plexus Flo Ware (4) | Rhapsody (7) |
| Popkins Systems Architect (2) | RKB Work Frame (4) |
| Power Designer (7) | Rose 98i (7) |
| Power Flow (1) | Route Builder Omni Desk (4) |
| Power Flow Team Flow Process Wise (4) | SA/Object Architect (7) |
| Power Work (1) | SAData Architect (7) |
| Powerproject (2) | SAP Business Workflow (1) |
| Powerway (1) | SDT (7) |
| Pragmatica (7) | SDW (1) |
| Pro Model (5) | Select Enterprise (7) |
| Pro Sim (6) | SES/objectbench (7) |
| Procedure Analysis amp Design (1) | Silverrun Professional Series (7) |
| Procedure Writer 9000 (2) | Sim View (6) |

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| SIMAN amp ARENA (2) | Tool Builder (7) |
| SIMUL8 (6) | TOP-IX (2) |
| Smart Flow 98 (1) | Total Quality management Software |
| Smart Stream. (4) | TQMS (1) |
| Smarthire (2) | Ultimus (1) |
| Soft Modeler Business (7) | Value-Questr (3) |
| Softwarethrough Pictures Booch (7) | Vantage Team (7) |
| Softwarethrough Pictures IM (7) | Vectus (1) |
| Softwarethrough Pictures OMT (7) | Viewstar (1) |
| Softwarethrough Pictures SE (7) | Viewstar Workbench (2) |
| Softwarethrough Pictures UML (7) | Visible Analyst Workbench (7) |
| Solving Right (2) | Visual Thought (7) |
| SPARKS G2 (2) | Visual UML (7) |
| SPC-PC IV (2) | Visual Workflow (1) |
| SPCpack for Windows (2) | With Class 98 (7) |
| Spectrum HR (2) | Witness (1) |
| Spreadsheet (2) | Wizdom Works (1) |
| SSADM (7) | Work Fast (4) |
| Statemate Magnum (7) | Work FLOW SQL (1) |
| Statistical Process Control (2) | Work Flow.2000 (4) |
| Struct Ware (5) | Work Flow.2020 (4) |
| Supersynch (2) | Work MAN (4) |
| Surveywin (2) | Work Vision (1) |
| System Specs (5) | Work Xpert (1) |
| Taskey Plus (2) | Workflow FONT FACESymbolmiddot |
| Team Flow (2) | FONTBPR (5) |
| Team Route (1) | Workflow Modeler (5) |
| Team Work (7) | World Wide Web Flow W4 (1) |
| The Electronic Workforce (4) | XBML (0) |
| The Vantive System (4) | XWorkflow (4) |
| The Workflow Factory (3) | |
| TI BDF (2) | |
| TI IEF (2) | |
| Time Phaser Global Work Scheduler (4) | |
| Tofs (7) | |
| Together C (7) | |
| Together J (7) | |

The Twelve Basic UML Diagram Types

B.1 Introduction

This appendix aims to explain the key features of the twelve most common UML diagrams, as described in the Specification (OMG, 2003). This forms a supplement to the writing contained in the main body of the thesis.

B.2 Structural Diagrams

The four diagrams in the Structural Diagram group give a model of the static application of the *structure* of the system in question. They are also sometimes known as static models (OMG, 2003). The group includes the:

- Class Diagram;
- Object Diagram;
- Component Diagram; and
- Deployment Diagram.

B.2.1 Class Diagram and Object Diagram

Before describing the Class and Object diagrams, it is first important to explain clearly what is meant by the terms “class” and “object”. The OMG, the writers of the UML specification (2003) define a class as being “a description of a set of objects that share the same attributes, operations, methods, relationships and semantics”. It therefore follows that an object is “an entity with a well-defined boundary and identity that encapsulates state and behaviour...an object is an *instance* of a class”.

In effect a class is a category of objects and object is an instance of a class, which inherits all the characteristics of the class. A class is represented by a solid-outlined rectangle divided into three horizontal parts. The top compartment contains the name of the class and other general properties, such as the stereotype. The middle section contains a list of the attributes

of the class, while the bottom compartment lists all the operations (or behaviours) that the class can carry out (or have done to it).

An object is a particular instance of a class and its attribute values must fit within those prescribed by the class. The object can carry out (or have done to it) those operations that are permissible by its class. An object looks identical to a class except that the name (and stereotype, if any) is underlined. Note that each class must have a unique name and, similarly, each instance of that class (object) must be unique. The class name must have no spaces and each word is capitalised. The object name should be all lower case with spaces. This allows them to be more easily distinguished between. The classes and objects can be shown at whatever level of details is helpful (see Figure B.1).

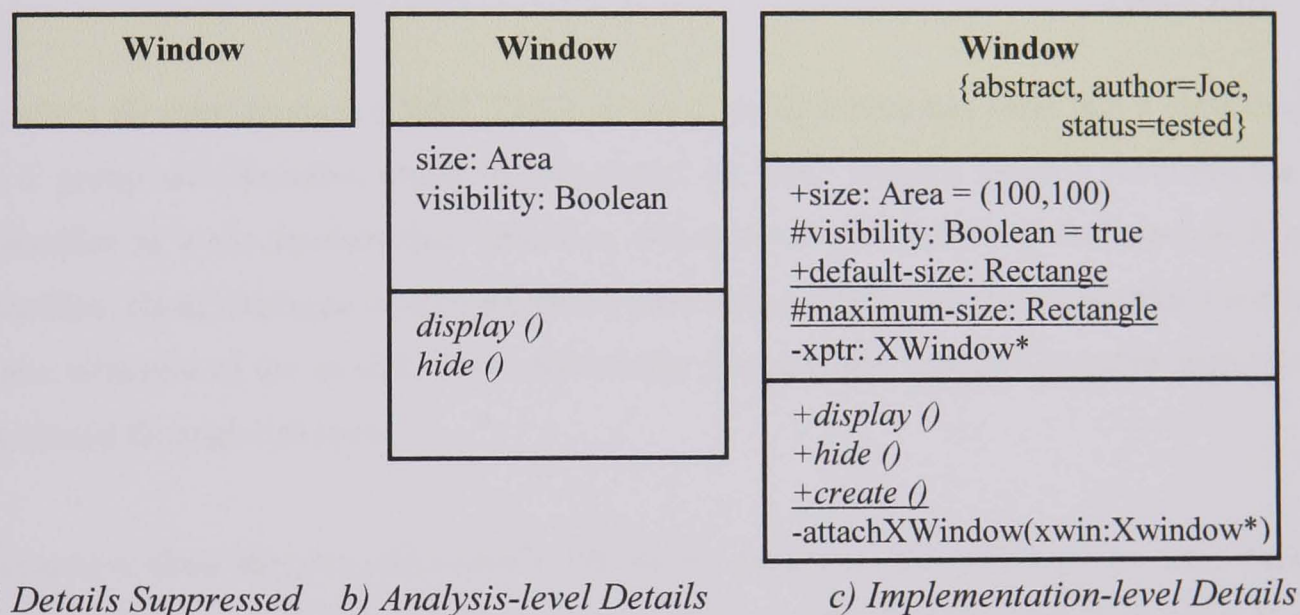


Figure B.1: Class notation (after OMG, 2003)

Attributes can be marked (Sparx, 2000) as:

- Private - not visible to callers outside the class (-);
- Protected - they are only visible to children of the class (#); or
- Public - they are visible to all (+).

The diagrams in this thesis have been produced in Enterprise Architect. The conventions for drawing objects and classes are extended. The class name must have no spaces and each word is capitalised. The object name should be all lower case with spaces. This allows them to be more easily distinguished between.

The Class and Object Diagrams are sometimes combined into one model. This is generally referred to as a Domain Model (Larman, 2002), Logical Model (Sparx, 2000; 2003), or

Conceptual Model (Larman, 2002). The overriding goal is “to provide a visual representation of conceptual classes or real-world objects in a domain of interest” (Fowler, 1999).

According to the OMG, a class diagram is:

“A diagram that shows a collection of declarative (static) model elements, such as classes, types, and their contents and relationships”

OMG, 2003

The OMG defines an object diagram as being:

“A diagram that encompasses objects and their relationships at a point in time. An object diagram may be considered a special case of a class diagram or a collaboration diagram”

OMG, 2003

Reading the specification (OMG, 2003) in more detail it becomes clear that a class diagram is a group of Classifier elements connected by their various (static) relationships. A Classifier is a mechanism that describes behavioural and structural features; such as an interface, class, data type or component. Essentially, a class diagram is a graphic view of the static structure of the model. The relationship between the various Classifier elements can be shown through linkages.

Because a class diagram can contain interfaces, packages and relationships (and instances such as objects and links) as well as just classes it “would be more logical to call it a “static structural diagram” but “class diagram” is shorter and well established” (OMG, 2003). The object diagram is a graph of instances, including objects and data values. It is in fact, a static instance of a class diagram, showing a “snapshot of the detailed state of a system at a point in time” (OMG, 2003). Object diagrams are actually a special case of a class diagram – one that contains only objects and no classes (rather than both). They are generally only used to show examples of data structures..

In the UML a Classifier is easily recognisable as it is represented by a rectangular icon. The class element is by far the most common of the three (class/object, interface and data type). The classes are declared in the class diagram and then used in most of the other diagram types.

B.2.2 Component Diagram

According to the OMG, a component diagram is:

“A diagram that shows the organizations and dependencies among components”

OMG, 2003

The OMG defines a component as being:

“A modular, deployable, and replaceable part of a system that encapsulates implementation and exposes a set of interfaces. A component is typically specified by one or more classifiers (e.g. implementation classes) that reside on it, and may be implemented by one or more artefacts (e.g., binary, executable, or script files”.

OMG, 2003

The Component Diagram is “geared expressly towards computer systems” (Shmuller, 1999). The diagram shows the relationship between software components, their dependencies, communication, location and other conditions (Sparx, 2000). The diagram is useful for exposing interfaces, which are visible entry points or services that a component is advertising and making available to other software components or classes. Each component may be made up of many internal classes and packages of classes, or may even be made up of packages of smaller components (Sparx, 2003). Although this suggests the idea of “nesting”, there may be limited value because the nesting is of components (which may or may not be identical) rather than process. Thus, it neither represents the ideas of fractals nor nested processes (Capra, 1996).

However, components can have requirements attached to them, which act as contractual obligations of the service that they will provide in the model (Sparx, 2003). In addition, they may have constraints attached, indicating the environment in which they can perform; such as pre-conditions and post-conditions (what must be true before and after it performs its functions). It is also to write scenarios, which are descriptions of the basic path through the functioning of the component (working perfectly, as well as with exceptions errors, and other conditions). All of this, particularly with regard to the constraints, suggests that the principles, if not the form, of a component diagram, could be of use where the interaction of components, and constraints, is of particular interest (Goldratt, various). This is because, although a component does not have its own features (e.g. attributes and operations) it acts as a container for other classifiers that are defined with feature, therefore exposing a set of interfaces which represent the services provided by the elements within the component.

It is interesting to note that such interfaces may contain dependencies. This is defined very differently to the CMAM definition, which relates to the amount of “joint” evidence between two child processes. The OMG definition is:

“A relationship between two modeling elements, in which a change to one modeling element (the independent element) will affect the other modeling element (the dependent element)”

OMG, 2003

This distinction in definition of dependency is a clear reminder of the care that must be taken with language usage, particularly when attempting to apply one methodology in a new field. It also reminds us of the fact that the commonly accepted form of a word can be misleading, thus people working together must ensure that they employ a consistent vocabulary.

B.2.3 Deployment Diagram

The OMG define a deployment diagram is:

“A diagram that shows the configuration of run-time processing nodes and the components, processes and objects that live on them. Components represent run-time manifestations of code units”

OMG, 2003

In this context, a node is something with memory and processing services (Larman, 2002). Essentially, the Deployment Diagram shows the physical architecture of a computer-based system, such as the computers and devices, their connections to one another, and the software that sits on each machine (Schmuller, 1999).

Due to the specific nature of this model type (and the limited iconography of cubes with lines linking them) it is not obviously applicable to this type of process thinking. However, one could think of incidences where it could be used in Information Theory (Capra, 1996) or in a Knowledge Management project.

B.3 Behaviour Diagrams

The five Behaviour Diagrams are so called because they represent aspect of the dynamic *behaviour* of the system. They are also sometimes referred to as the dynamic models (OMG, 2003). They are the:

- Use Case Diagram;
- Activity Diagram;
- Statechart Diagram;

- Sequence Diagram; and
- Collaboration Diagram;

B.3.1 Use Case Diagram

A use case diagram is “a diagram that shows the relationships among actors and use cases within a system” (OMG, 2003). An actor can have several classes of behaviour, “a coherent set of roles that users of use cases play when interacting with these use cases. An actor has one role for each use case with which it communicates” (OMG, 2003). A use case [class] is “the specification of a sequence of actions, including variants, that a system (or other entity) can perform, interacting with actors of the system” (OMG, 2003).

In the simpler terms provided by Geoffrey Sparx (Sparx, 2000), a Use Case model “describes the functionality of the system – what the system will do for the users in order to get some useful work done. It also helps to layout the actors or users of the system and their role in running the system”. The “actors” can be a human or a machine entity carrying out some meaningful work (using the system). The set of use cases an actor has access to defines their overall role in the system and the scope of their action.

It is important to note at this point that the actors are action “on” the system. Thus, they can be compared to stakeholders in the case study system. They are placing some demand on the organisation in order to get some meaningful “work” from it. The “work” can be loosely interpreted as, for example, “enjoyment of reservoir”, “conserved environment” or “electricity”. In the author’s terms, it is a demand on the system that is put into place at the boundary of that system. In the case of an electricity customer, that boundary will correspond with the boundary of the organisation, but in the case of a stakeholder who is within that meta-system (such as a member of staff, or a machine) the boundary may be around a sub-system of the organisation.

Figure B.2 gives a simple example of a Use Case diagram adapted from the latest version of the UML specification (OMG, 2003).

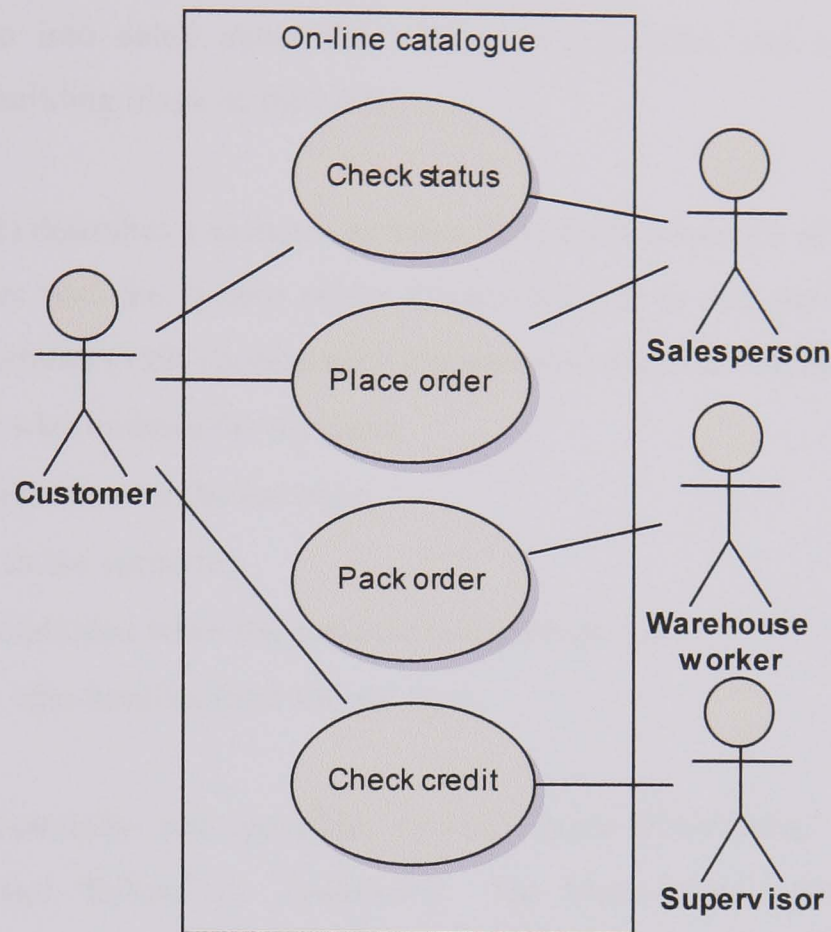


Figure B.2: An Example Use Case Diagram

The essence of the Use Case Diagram is that “it’s a tried-and-true technique for gathering system requirements from a user’s point of view” (Schmuller, 1999). The formal specification of a Use Case includes (Sparx, 2003):

- Requirements;
- Constraints; and
- Scenarios (also known as Use Case Instances).

The requirements define what a Use Case must provide to the end user (Actor). They are in effect a “contract that the Use Case will perform some action or provide some value to the system” (Sparx, 2003). This idea of contracts will be touched on again later. The constraints are formal rules and limitations under which the Use Case must operate. They usually comprise of pre-, post- and invariant conditions. Considering the example above, the “Check status” use case may return a condition of “status OK”, which then acts as a pre-condition to the “Place order” use case. This interrelationships and sequential dependency of process is expressed more clearly in some of the other behaviour / dynamic diagrams (e.g. the sequence diagram).

The specification (OMG, 2003) defines a scenario as “A specific sequence of actions that illustrates behaviours. A scenario may be used to illustrate an interaction or the execution of a use case instance”. There are a number of publications (e.g. Cockburn, 2001; Larman, 2002) that go into detail about the writing of use cases and scenarios as they are a fundamental building block of the UML.

Larman (2002) describes a scenario as being “a specific sequence of actions and interactions between actors and the system under discussion.....It is one particular story of using a system”. Schuller (1999) breaks each use case into a textual list, detailing the:

- Actor who initiates the use case;
- Preconditions for the use case;
- Steps in the scenario;
- Postconditions when the scenario is complete; and
- Actor who benefits from the use case.

There are essentially two possible scenario types (Cockburn, 2001; Larman, 2002): “successful” and “failure” or “alternate”. The Main Success Scenario for the use case “Check Credit” in the use case diagram in Figure B.2 would be for the customer to have sufficient credit to allow the transaction to continue. An “alternate” scenario would be for the online catalogue company to inform the customer and ask for another form of payment. A “failure” scenario would only occur if the customer was unable to achieve his goal of placing an order.

Cockburn (2001) provides a very comprehensive description of writing use cases, and Larman (2002) even offers two formats for their presentation (one or two columns). An example, used for the case study, is given in Chapter 9.

B.3.2 Activity Diagram and Statechart Diagram

The latest version of the UML specification (OMG, 2003) several pages each to Activity Diagrams and Statechart Diagrams. However, as the definitions below reveal, they are very closely related to one another.

“An activity graph [diagram] is a variation of a state machine in which the states represent the performance of actions or subactivities and the transitions are triggered by the completion of the actions or subactivities. It represents a state machine of a computation itself.....An activity diagram is a special case of a state diagram in which all (or at least most) of the states are action or subactivity states and in which all (or at

least most) of the transitions are triggered by completion of the actions or subactivities in the source states"

OMG, 2003

"A statechart diagram can be used to describe the instances of a model elements such as an object or an interaction. Specifically, it describes possible sequences of states and actions through which the element instance can proceed during its lifetime as a result of reacting to discrete events....Statechart diagrams represent the behavior of entities capable of dynamic behavior by specifying its response to the receipt of event instances. Typically it is used for describing the behaviour of class instances, but statecharts may also describe the behaviour of other entities such as use-cases, actors, subsystems, operations, or methods"

OMG, 2003

Essentially, an activity diagram *is a* special case of a state machine, while a statechart diagram *shows* a state machine. A state machine is a "behavior that specifies the sequences of states that an object or an interaction goes through during its life in response to events, together with its responses and actions" (OMG, 2003).

Geoffrey Sparx (2001, 2003) bundles together Activity Diagrams, State Charts (another term for Statechart Diagrams) and Sequence Diagrams into what he refers to as "The Dynamic Model". According to Sparx (and the author agrees) the only difference between a Sequence and Collaboration diagram is the layout, as they are semantically identical. More details of these are given in the following section.

The Activity diagram, as the name suggests is used to "show a sequence of activities" (Larman, 2002). In fact, it not only shows different processes (or work flows) in the system, how they start and where they finish, but also gives decision points and allows for parallel processing to take place as shown in the example in Figure B.3 (Fowler and Scott, 1999). The Activity diagram is often used to model business activities (such as "Selling Books" or "Managing Inventory") and may be at a very high level (Sparx, 2001). The standard Activity diagram notation has been extended to help it portray business processes more accurately.

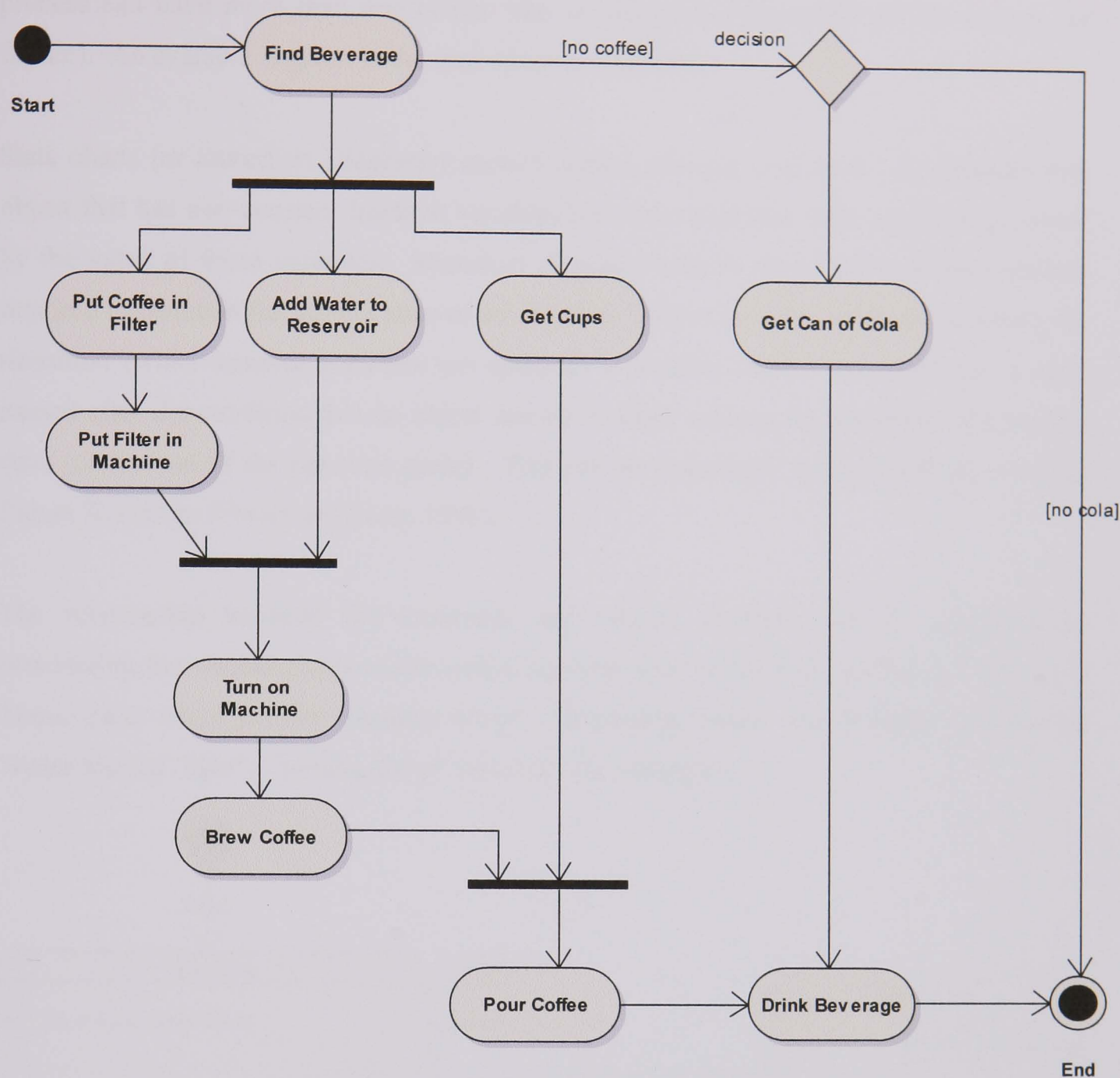


Figure B.3: Example of an Activity Diagram

The same diagram can also be expressed as a so-called “Swimlane” diagram (OMG, 2003; Schmuller, 1999), which allows actions and subactivities to be organised into vertical swimlanes, which often correspond to organisational units in a business model.

This is merely a visual aid, as the contents vary little from that of the activity diagram. Although the swimlane does also have some visual similarity with the sequence diagram (described below) the difference is that it does not model messages passing from one object to another, but instead demonstrates which part of the organisation (which may be a package in a package model) takes responsibility for the process in question. The OMG (2003) stipulates that while transitions may cross lanes, each action is assigned to one swimlane. This provides some practical difficulties, where, to avoid the silo thinking recognised by Rummler and Brache (1995) it is recognised that one process is delivered by more than one department. However, it does follow the view of Blockley and Godfrey (2000) that no

process can have more than one owner who is ultimately responsible for its success (or failure). An example is given in the case study in Chapter 9.

State charts (or Statechart Diagrams) capture system changes over time. At run-time, any object that has non-constant instance variables has some potential state, which is governed by the value of those variables. Statechart diagrams help to reveal the instance variables required to maintain the current state of an object as well as the pre-conditions necessary for transition (when instance variables are updated) to another state. The States are usually named after the condition that an object can be in while waiting for transition into another state (or the end of the run-time cycle). This can be understood more clearly by studying Figure B.4 (from Fowler and Scott, 1999).

The relationship between the statechart and activity diagram can be visualised by considering the various states of the coffee machine used to brew the coffee in Figure B.4. These states could include “heating water”, “displaying ‘ready’ signal light”, “displaying ‘water needed’ light”, “cooling down” and “off” for example.

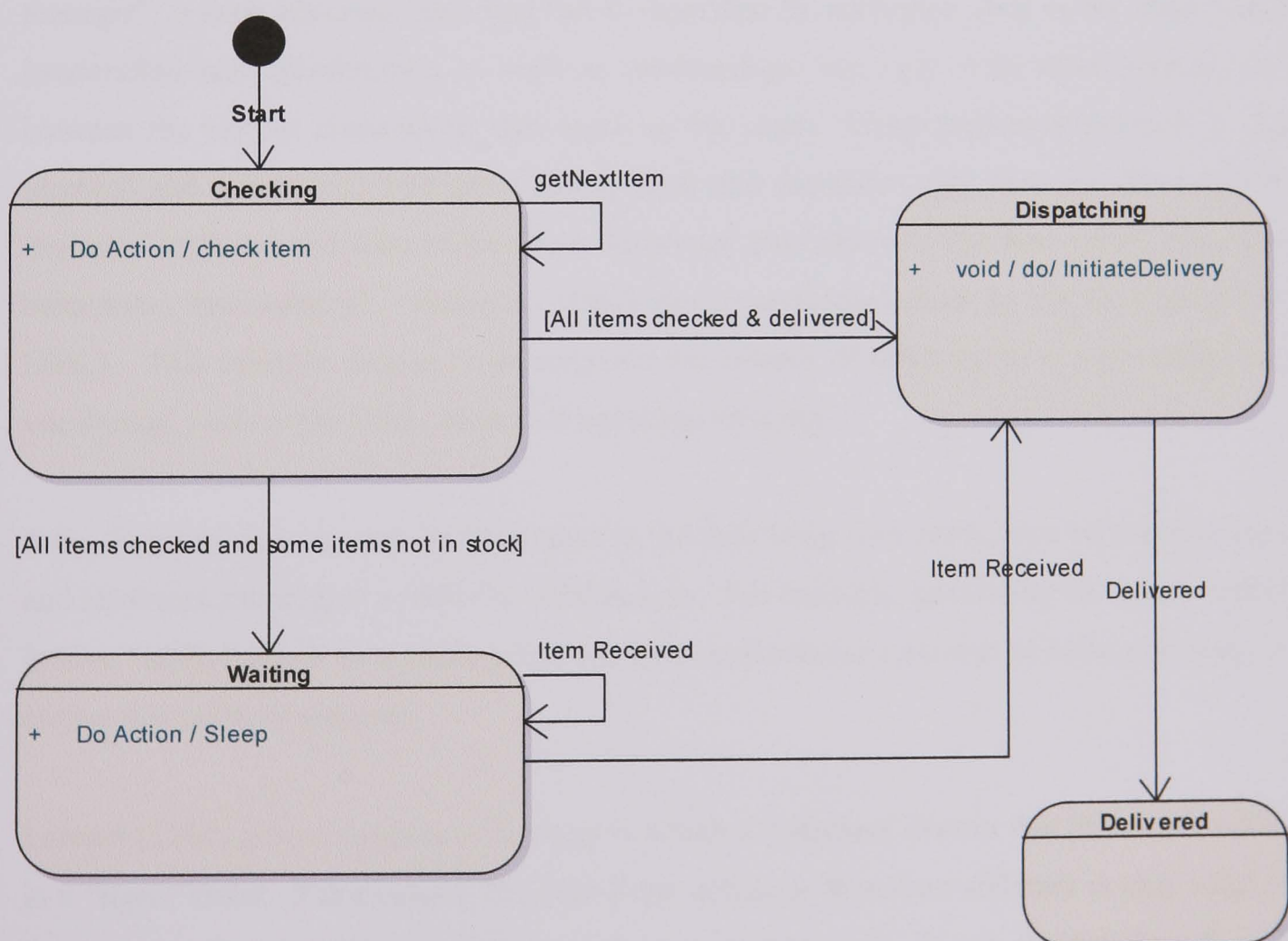


Figure B.4: Example of a Statechart Diagram

Schmuller (1999) gives only a cursory explanation of Statechart Diagrams, explaining that:

“At any given time, an object is in a particular state. A person can be a newborn, infant, child, adolescent, teenager, or adult. An elevator is moving upward, stopped, or moving downward. A washing machine can be in the soak, wash, rinse, spin or off state”.

Schmuller, 1999

It is interesting to note that, while Sparx (2001) refers to Statecharts as modelling class behaviour, the OMG (2003) distinguishes between behaviour and state. The behaviour is described as “the observable effects of an operation or event, including its results” and is represented by operations, methods, and state machines. Meanwhile a state is “a condition or situation during the life of an object during which it satisfies some condition, performs some activity, or waits for some event” and is represented by attributes and relationships.

These definitions are helpful for process thinking. For example, Blockley and Godfrey (2000) develop a process model for a chair, which begins with the top-level process of “being a chair hand-crafted for comfort”. This description does not make intuitive sense. However, if one considers “being a chair” as a state, synonymous with that of “being a teenager”, it soon becomes clear that this is described by attributes, such as the chair being handcrafted and comfortable, as well as relationships, not only with other objects, but between the various components that make up the chair. These relationships (such as the physical and special one between a dining chair and the table) may have an effect on the desirable attributes and state of the chair. However, the chair will also have series of nested behaviours “maintaining”, “sitting in” which can be performed on or by the chair (as in the UML). This example begins to demonstrate the benefit of referring to a well-established vocabulary, such as the UML, to describe process-thinking.

It has become clear, as will be illustrated in the following case study, that both behaviours and attributes can trigger a need for child holons. For example, generating electricity safely (where “safely” might be considered an attribute) will require a number of child processes to ensure that safety is assured.

Larman (2002) gives examples of the way in which a statechart ensures that processes occur in a “legal” order. For example, the Edit-Paste action in Windows software is only valid if there is something has already been pasted on the “clipboard”. If not, the “clipboard” will have an “empty” state, which precludes the pasting action. In this sense, the object of the “clipboard” is clearly state-dependent.

Essentially, the statechart describes how any given object will react to an event at any given time (depending on the state that it is in). Larman (2002) defines the three event types as follows:

- (i) *External (or system) event* – caused by something (e.g. an actor) outside the system boundary;
- (ii) *Internal event* – caused by something inside the boundary (including a message or signal sent from another internal object); and
- (iii) *Temporal event* – caused by the occurrence of a specific date and time, or passage of time.

Larman (2002) prefers to only represent temporal and external events in statecharts, relying on interaction (collaboration) diagrams to demonstrate the passing of messages within objects in the system, which could be called internal events. An example of a temporal event in the case study might be a dam safety inspection, as these are required at stated intervals and are neither triggered (directly) by an external actor nor an internal object.

B.3.3 Sequence Diagrams and Collaboration Diagrams

Sparx (2001,2003) describes Sequence Diagrams and Collaboration diagrams as being “semantically identical” as both describe the “interactions between object instances at run-time”. This is true to an extent, and explains why the OMG (2003) refers to them both as “Interaction Diagrams”. The specification goes onto explain that:

“The description of behavior involves two aspects: 1) the structural description of the participants and 2) the description of the communication patterns. The structure of Instances playing roles in a behavior and their relationships is called a Collaboration. The communication pattern performed by Instance playing the roles to accomplish a specific purpose is called an Interaction.....Interaction diagrams come in two forms based on the same underlying information, specified by a Collaboration and possibly by an Interaction, but each form emphasizes a particular aspect of it.....A sequence diagram shows the explicit sequence of communications and is better for real-time specifications and for complex scenarios. A collaboration diagram shows an Interaction organized around the roles in the Interaction and their relationships. It does not show time as a separate dimension, so the sequence of communications and the concurrent threads must be determined using sequence numbers.”

OMG, 2003

Sequence Diagrams (also known as Systems Sequence Diagrams, or SSD) are like a dynamic and more detailed form of a Use Case Diagram. They show, for a particular scenario of a use case, the events that the external actors generate, their order, and inter-system events. Larman (2002) explains that “all systems are treated as a black box: the emphasis of the diagram is events that cross the system boundary from actors to systems”. A

sequence diagram should be made for the main “successful scenario” of the use case as well as any frequent or complex alternative scenarios.

The sequence diagram illustrates interactions using a “fence format” where time is shown on a vertical line (travelling from the top to the bottom). It is useful in that it clearly shows the sequence in which the messages must be sent. However, once several classes are required, each with their own vertical “fence” the diagram can quickly become very large in the horizontal diagram as each new object is added to the right hand side.

Collaboration diagrams illustrate object interactions in a network format, with objects placed anywhere on the diagram. This option is much more economical on space, allowing more flexibility to add objects. It is also much better at illustrating complex branching, iteration and concurrent behaviour. However, the diagram does not explicitly give an indication of the sequence in which the messages must be passed. Thus a more complex notation, involving numbering the messages, is required.

Figures B.5 and B.6 give simplified examples of a sequence and collaboration diagram that both demonstrate the same interaction. These diagrams, taken from Larman (2002) enact the following scenario:

- The message *makePayment* is sent to an instance of a *Register*. The sender is not notified.
- The *Register* instance sends the *makePayment* message to a *Sale* instance.
- The *Sale* instance creates an instance of a *Payment*.

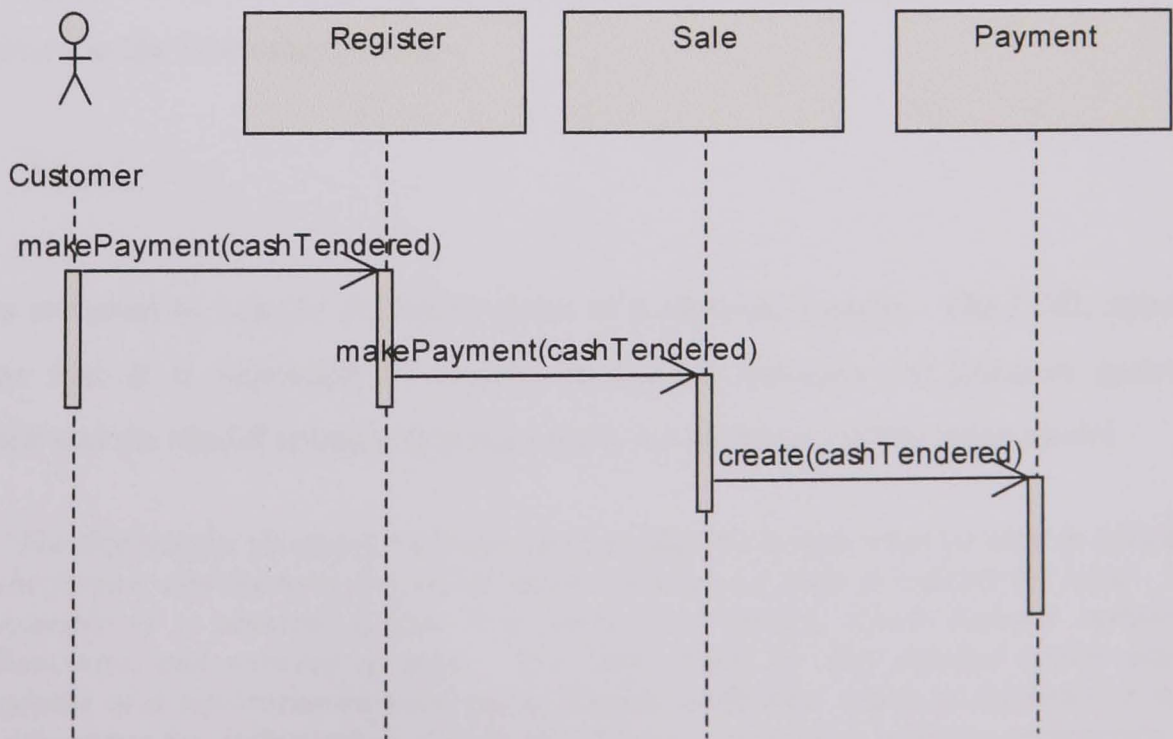


Figure B.5: Example of a Sequence Diagram (Sparx, 2001)

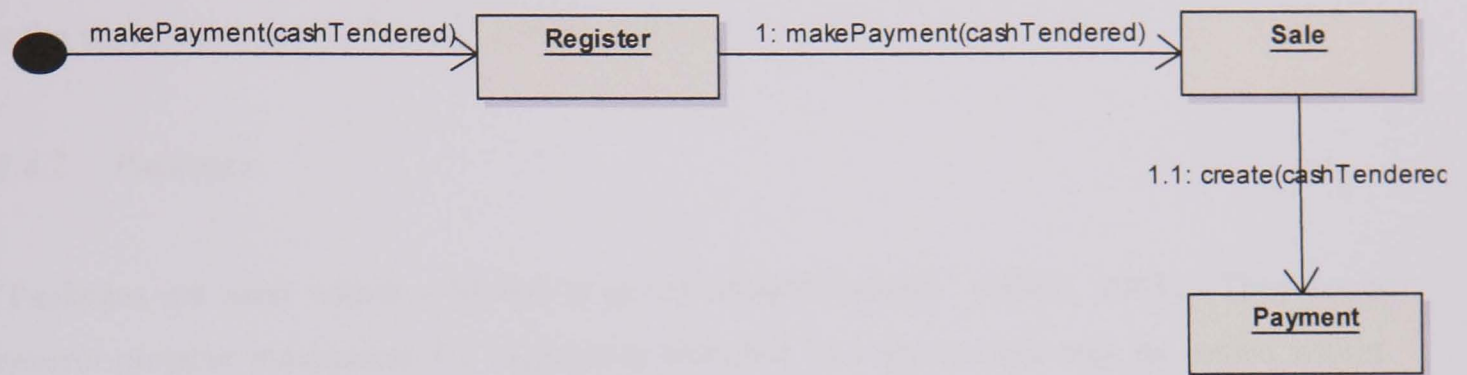


Figure B.6: Example of a Collaboration Diagram

It soon becomes clear from examining the figures and reading the description, why Sparx (2001, 2003) recommends that interaction diagrams are used for the passing of internal messages, rather than the statecharts, described above. They are a clear and convenient method for capturing this information.

B.4 Model Management Diagrams

There are three diagrams within the UML that are used to organise and manage the various modules within an application. They are known as:

- Models
- Packages; and
- Subsystems.

Essentially, all three act as grouping units for other model elements. Each is described in more detail in the following sections.

B.4.1 Models

Models are used to capture different views of a physical system. The UML specification explains that it is important to clearly distinguish between the *physical system* being modelled and the model element that represents the physical system in the model.

“For this reason, we consistently use the term physical system when we want to indicate the former, and the term (top-level) subsystem when we want to indicate the latter. An example of a physical system is a credit card service, which includes software, hardware, and wetware (people). The UML model for this physical system might consist of a top-level subsystem called CreditCardService, which is decomposed into subsystems for Authorization, Credit and Billing. An analogy with the construction of houses would be that the house would correspond to the physical system, while a blueprint would correspond to a model, and an element used in a blueprint would correspond to a model element”.

OMG, 2003

The choice of model depends on the purpose of that model. Thus, the model completely describes “those aspects of the physical system that are relevant to the purpose of the model, at the appropriate level of detail” (OMG, 2003).

B.4.2 Packages

“Packages are used within a Model to group ModelElements” (OMG, 2003). They are a general purpose mechanism for organising elements into groups and may be nested within other packages. Schmuller (1999) uses packages to group together functionalities according to the person who would carry them out. In the example he sites, where the system being developed is for a restaurant, the packages include: server, chef, manager, assistant, bartender and coat-check clerk. The icon for a package looks like a tabbed folder icon.

B.4.3 Subsystem

The UML specification (OMG, 2003) defines a subsystem as “a grouping of model elements that represents a behavioral unit in a physical system. A subsystem offers interfaces and has operations. In addition, the model elements of a subsystem can be partitioned into specification and realization elements”.

C.1 Introduction

This appendix contains examples of the “Demand and Response” tables that were created to ensure the robustness of the methodology. These are given for a linear part of the case study system. In practice, the interactions are more complex because every parent holon will place a demand on more child (if there is only one child then it is the parent). However, this serves to illustrate the way in which the method works.

C.2 System of Interest

The system being modelled comprises the processes that occur when a customer demands electricity (to turn on a light, for example). Note that several of the actors, including the customer, the switch and the distribution system are outside the part of the model given in the case study (although Scottish and Southern Energy, plc. does have a Transmission and Distribution business). Also, several of the actors sit at what are essentially contract boundaries. This is often the case because each demand and response pair is analogous to contract, even if it is an unwritten one. The following table summaries the above:

Table C.1: Identifying Actors and Goals from External Events

| From Actor | External Event | To Actor | Goal |
|--|---------------------|--------------------------------|---|
| Customer | Flicks the switch | Asking the Switch | Turn on the light |
| The Switch | Demands Electricity | From the Domestic Power Supply | To power the light |
| The domestic power supply (Distribution Transformer) | Demands Electricity | From the Electricity Supplier | To meet the domestic electricity demand |
| The Electricity Supplier | Demands Electricity | From the Electricity Generator | To supply the domestic electricity power supply |
| The Electricity Generator | Demands Electricity | From the Generator Machine | To supply the Electricity Supplier with Electricity |
| The Generator Machine | Demands Water | From the Penstock System | To enable the turbine to spin the rotor which results in electricity generation |
| The Penstock System | Demands Water | From the Reservoir System | To supply the Generator Machine with water |
| The Reservoir System | Demands Water | From the Environment | To supply the penstock system with water |

The customer asks the *electricity supplier* to supply it with electricity in accordance with his requirements. The *electricity supplier* agrees to supply the customer with electricity according to their conditions. The customer agrees to the *electricity supplier*'s conditions. The *electricity supplier* supplies the electricity according to the customer's requirements. The customer pays for the electricity according to the *electricity supplier*'s conditions.

| Primary actors | Interests |
|--|---|
| <u>Customer (customer)</u> | Wants to receive electricity according to his requirements |
| <i>electricity supplier (organisation)</i> | Wants to make money from selling electricity according to its conditions. |
| Precondition | The <u>customer</u> identifies a need (from external stimuli) for electricity |
| Success guarantee (post condition) | <u>Customer</u> has received electricity according to his requirements and <i>company</i> has received payment according to its conditions. |
| Shadow usage cases | <u>Customer</u> – <i>customer complaints watchdog</i> . <u>Customer complaints watchdog</u> to <i>company</i> . |

| | Prompts | Customer Requirements | Electricity Supplier Requirements |
|---|--|---|---|
| 1 | What do I need from this transaction? | Electricity | Money |
| 2 | How much of it do I want (from this transaction)? | Enough to light my home when I want to and keep it warm (XkWh) | Enough to pay shareholder dividends at Y%, pay staff, service loans and pay for repairs and bills – Cost + £X per kWh |
| 3 | When do I want it? | On demand | Monthly payments by direct debit or quarterly within 7 days of billing (after use) |
| 4 | Where do I want it? | At the 'plug-face' | In my bank account. |
| 5 | How do I want it (quality)? | Ready-generated and of a steady voltage through the mains | Regularly, paid-in full, preferably before supply, but if not within 7-28 days after |
| 6 | How much will I give for it (depends on values and perceived level of need)? | A bit extra for renewable - or no more than British Gas – or no more than my best friend. | The required amount of electricity, up to a limit of ZkWh between bills being paid. |
| 7 | Why do I need it (why do I value it)? | I want to be able to see in the dark and be warm in winter | If I don't earn more than costs then eventually I will go bankrupt and people will lose their jobs. |
| 8 | Who will I get it from? (linked to 6) – preferred supplier | Green supplier – well-known company – cheapest on market | People on medium to high incomes with big houses and good credit ratings |

| Prompts | | Customer Constraints | Electricity Supplier Constraints |
|---------|--|--|--|
| 1 | What is prompting me to carry out this transaction? | Need for light – pointed out by bumping into furniture. | The bank is charging £Xm in interest on my borrowings and I need to pay the bills and salaries |
| 2 | What is my capacity for using and storing the product? | Enough to heat all my radiators to max and light all my lamps | I don't want to earn more than £Xm in one year or I'll be clobbered by tax |
| 3a | When is the earliest that I can get it? | Now | By direct debit one month before supply or within 7 days after |
| 3b | When is the latest I can get it? | Just before I get pneumonia | If the don't pay within 28 days of supply I instigate the "sue" usage case. |
| 4 | Can I have it where I want it? | Yes, my home is connected to the mains | Preferably by direct debit direct to my account, or else by check |
| 5 | What quality is available? | I can check with the Which? Guide to see which company offers the best service | My competitors have nicked the best customers – I may need to take smaller usage clients. |
| 6 | How much can I afford to give for it? | £X per month | On average, Xkwh per person – but if I build more plant, Ykwh |
| 7 | How much is the minimum that I need? | Enough to heat one radiator and one lamp | On average, cost price + £X – but I will support some "loss leaders" for loyalty in the future |
| 8 | Who can I get it from? – possible suppliers | Are there any suppliers of this product? | Potential customer base includes all homes on mains – could expand by instigating "new homes on mains" usage case. |

The reverse usage case has the following successful scenario:

The **electricity supplier** wants to sell electricity according to its requirements. The **electricity supplier** approaches a *potential customer* and offers to sell the *customer* electricity according to its requirements. The *customer* agrees to buy electricity from the **electricity supplier** according to his conditions. The *customer* pays for the electricity in accordance with the **electricity supplier**'s requirements. The *electricity supplier* supplies the electricity in accordance with the *customer*'s conditions.

Electricity Supplier Interactions (passed on through transformer)

The **electricity supplier** asks the *electricity manufacturer* to supply it with electricity in accordance with its requirements. The *electricity manufacturer* agrees to supply the **electricity supplier** with electricity according to its conditions. The **electricity supplier** agrees to the *electricity manufacturer*'s conditions. The *electricity manufacturer* supplies the electricity according to the **electricity supplier**'s requirements. The **electricity supplier** pays for the electricity according to the *electricity manufacturer*'s conditions.

| Primary actors | Interests |
|---|--|
| Electricity supplier (customer) | Wants to receive electricity according to its requirements |
| Electricity manufacturer (organisation) | Wants to make money from selling electricity according to its conditions. |
| Precondition | The electricity supplier has at least one customer that is demanding electricity |
| Success guarantee (post condition) | Electricity supplier has received electricity according to its requirements and electricity manufacturer has received payment according to its conditions. |
| Shadow usage cases | |

| | Prompts | Electricity supplier Requirements | Electricity manufacturer Requirements |
|---|--|--|---|
| 1 | What do I need from this transaction? | Electricity | Money |
| 2 | How much of it do I want (from this transaction)? | Varies according to market – e.g. cost of electricity from other sources – but in total, enough to meet customer demands | Enough to pay shareholder dividends at Y%, service loans, pay staff and pay for repairs and bills – Cost + £X per kWh |
| 3 | When do I want it? | Tiered - x amount with y minutes, z amount within Q hours and s amount in r days | Full payment within 28 days |
| 4 | Where do I want it? | Direct to my transmission and distribution set-up | In my bank account. |
| 5 | How do I want it (quality)? | Ready-generated and of the correct voltage (stepped up or down) for my transmission network | Regularly, paid-in full. |
| 6 | How much will I give for it (depends on values and perceived level of need)? | Negotiable according to cost of electricity from other sources | The required amount of electricity, up to a limit of ZkWh between bills being paid. |
| 7 | Why do I need it (why do I value it)? | My customer is demanding it and I can make a profit from the sale. | If I don't earn more than costs then eventually I will go bankrupt and people will lose their jobs. |
| 8 | Who will I get it from? (linked to 6) – preferred supplier | UK supplier because the cross-channel link is too expensive | Electricity supplier |

| Prompts | | Electricity supplier Constraints | Electricity manufacturer Constraints |
|---------|--|---|--|
| 1 | What is prompting me to carry out this transaction? | Customer demand for electricity | The bank is charging £Xm in interest on my borrowings and I need to pay the bills and salaries |
| 2 | What is my capacity for using and storing the product? | My transmission and distribution network has a capacity of XMwH – transformer has capacity of Y MW | Favourable tax set-up means I can earn as much as I like as long as I invest carefully |
| 3 a | When is the earliest that I can get it? | As negotiated in point 3 of requirements | Paid in advance, monthly for example |
| 3 b | When is the latest I can get it? | Within x seconds for promised electricity, longer if renegotiating. | If they don't pay within 28 days of supply I instigate the "sue" usage case. |
| 4 | Can I have it where I want it? | Yes, I have a transformer next to each of the manufacturer's generators. | Yes |
| 5 | What quality is available? | I have a balanced portfolio of various generators that I use according to the speed of demand | There are several large electricity suppliers that are thought to be long-term solvent. |
| 6 | How much can I afford to give for it? | Between x and y pence per kWh, depending on the market | On average, Xkwh per person – but if I build more plant, Ykwh |
| 7 | How much is the minimum that I need? | Enough to supply the demands of my existing customers | Cost price + a profit margin – although I can support some short-term losses when demand is low in return for contract tie-in which enables me to charge lots when demand is low |
| 8 | Who can I get it from? – possible suppliers | Currently from manufacturers where I own or lease the transformer – but I could expand to other manufacturers | Potential customer base includes all electricity suppliers, and if the law changes I may be able to supply direct (have a supplier within my own company) |

The reverse usage case has the following successful scenario:

The electricity manufacturer wants to sell electricity according to its requirements. The electricity manufacturer approaches a *potential electricity supplier* and offers to sell the *electricity supplier* electricity according to its requirements. The *electricity supplier* agrees to buy electricity from the electricity manufacturer according to its conditions. The *electricity supplier* pays for the electricity in accordance with the electricity manufacturer's requirements. The *electricity manufacturer* supplies the electricity in accordance with the *electricity supplier*'s conditions.

Electricity Manufacturer (Management) Interactions

The electricity manufacturer asks the *generation system* to supply it with electricity in accordance with its requirements. The *generation system* agrees to supply the electricity manufacturer with electricity according to its conditions. The electricity manufacturer agrees to the *generation system*'s conditions. The *generation system* supplies the electricity according to the electricity manufacturer's requirements. The electricity manufacturer pays for the electricity according to the *generation system*'s conditions.

| Primary actors | Interests |
|--|---|
| <u>Electricity manufacturer (customer)</u> | Wants to receive electricity according to its requirements |
| <i>Generation system (organisation)</i> | Wants to make money from selling electricity according to its conditions. |
| Precondition | The <u>electricity manufacturer</u> has at least one customer that is demanding electricity |
| Success guarantee (post condition) | <u>Electricity manufacturer</u> has received electricity according to its requirements and <i>generation system</i> has received payment according to its conditions. |
| Shadow usage cases | |

| | Prompts | Electricity manufacturer Requirements | Generation system Requirements |
|---|--|---|---|
| 1 | What do I need from this transaction? | Electricity | Money |
| 2 | How much of it do I want (from this transaction)? | Enough to meet electricity supplier's demands | Enough money to pay staff, repairs and regeneration costs |
| 3 | When do I want it? | As required by my agreement with the electricity supplier | At least just in time, but preferably months in advance to facilitate planning |
| 4 | Where do I want it? | At transformer | Provided to engineering manager |
| 5 | How do I want it (quality)? | At Xvolts | Paid according to company Quality Assurance methods |
| 6 | How much will I give for it (depends on values and perceived level of need)? | £Xm due to Government change in Green Fuel policy making refurbishment cost-effective | The required amount of electricity |
| 7 | Why do I need it (why do I value it)? | The electricity supplier is demanding it and I've agreed to its requirements | To ensure that I can keep providing electricity in the long term (and pay my staff) |
| 8 | Who will I get it from? (linked to 6) – preferred supplier | My generation system | My company management group |

| Prompts | | Electricity manufacturer Constraints | Generation system Constraints |
|---------|--|--|---|
| 1 | What is prompting me to carry out this transaction? | I need to meet electricity supplier demand | This is the process I enact – I exist to generate electricity |
| 2 | What is my capacity for using and storing the product? | As dictated by the electricity supplier – plus I have a couple of transformers of my own. | My capacity for generating electricity is kWh. and dependant on the weather and other variables |
| 3 a | When is the earliest that I can get it? | My generation system can provide X mWh within y seconds of request, R within S minutes of request, T within U hours and V within W days. | Dictated by internal Quality Assurance payment system |
| 3 b | When is the latest I can get it? | Within x seconds for promised electricity, longer if renegotiating. | Just before the company is sued for not paying staff or contractors for work rendered |
| 4 | Can I have it where I want it? | Yes, all my sets are functioning at the moment and feeding the electricity supplier's transformers as required | No, there is never enough money to refurbish everything, I have to weigh up the risks and spend money appropriately |
| 5 | What quality is available? | Electricity at required voltage to pass on to the electricity supplier's transformers | All money is dependable as from own company |
| 6 | How much can I afford to give for it? | I can run at a small loss for short periods but must average x pence per kW over the long term | Maximum generation is XkW at any one time. |
| 7 | How much is the minimum that I need? | Enough to supply the demands of the electricity suppliers | Enough to carry on with “just-in-time” repairs |
| 8 | Who can I get it from? – possible suppliers | My own generation system, (or other generators if for some unforeseen reason I cannot meet contracted supply level) | Upper echelons of the electricity manufacturing company |

The reverse usage case has the following successful scenario:

The **generation system** wants to sell electricity according to its requirements (i.e. there is a lot of rain and it wants to pass water through the sets, rather than spilling). The **generation system** approaches a *potential electricity manufacturer* and offers to sell the *electricity manufacturer* electricity according to its requirements. The *electricity manufacturer* agrees to buy electricity from the **generation system** according to its conditions. The *electricity manufacturer* pays for the electricity in accordance with the **generation system's**

requirements. The *generation system* supplies the electricity in accordance with the *electricity manufacturer*'s conditions.

Generation System (Management) Interactions

The generation system asks the *power station governor* to supply it with electricity in accordance with its requirements. The *power station governor* agrees to supply the generation system with electricity according to its conditions. The generation system agrees to the *power station governor*'s conditions. The *power station governor* supplies the electricity according to the generation system's requirements. The generation system pays for the electricity according to the *power station governor*'s conditions.

| Primary actors | Interests |
|--|---|
| <u>Generation system (customer)</u> | Wants to receive electricity according to its requirements |
| <i>Power station governor (organisation)</i> | Wants to receive a signal to tell it what speed to govern the turbine at and maintenance to continue being able to carry out job |
| Precondition | The <u>generation system</u> is experiencing a demand for electricity |
| Success guarantee (post condition) | <u>Generation system</u> has received electricity according to its requirements and <i>power station governor</i> has received payment according to its conditions. |
| Shadow usage cases | |

| | Prompts | Generation system Requirements | Power station governor Requirements |
|---|--|---|--|
| 1 | What do I need from this transaction? | Electricity | A signal to perform and maintenance afterwards |
| 2 | How much of it do I want (from this transaction)? | Enough to meet electricity manufacturer's demands | Signal to start, plus maintenance to ensure acceptable level of performance and risk |
| 3 | When do I want it? | As required by my agreement with the electricity manufacturer | Maintenance every X working hours – signal at least Y seconds before start up required |
| 4 | Where do I want it? | At generator | Signal at switch – maintenance where required |
| 5 | How do I want it (quality)? | At X volts | Clear signal through electrical system. Maintenance by experienced professional |
| 6 | How much will I give for it (depends on values and perceived level of need)? | £Zm to maintenance budget and refurbishment every Y years | The required level of control of the turbine speed |
| 7 | Why do I need it (why do I value it)? | The electricity manufacturer is demanding it and I've agreed to its requirements | To ensure that the turbine system operates as required |
| 8 | Who will I get it from? (linked to 6) – preferred supplier | Indirectly from the generator, by requesting that the governor initiates a production process (via the turbine) | The generation system management group and staff employed to maintain me |

| Prompts | | Generation system Constraints | Power station governor Constraints |
|---------|--|---|--|
| 1 | What is prompting me to carry out this transaction? | I need to meet electricity manufacturer demand | This is the process I enact – I exist to control the turbine process |
| 2 | What is my capacity for using and storing the product? | I can store potential energy in the system but once I have generated the electricity I have to pass it on to the transformers straight away | I can operate within safe margins as long as I am maintained according to my requirements. Signals can be programmed X hours in advance |
| 3 a | When is the earliest that I can get it? | My power station governor can get the turbine to full working speed within X minutes of request. My spinning reserve set can produce Y kW within P seconds of request. | I can't make the turbine spin any faster than the water power and friction permit |
| 3 b | When is the latest I can get it? | I am considered to have failed if I do not provide the electricity supplier with electricity (on behalf of the electricity manufacturer) within X seconds of the request. | Fuzzy – but the longer apart the maintenance is the more likely I am to fail to start the turbine system. The signal must be received at least X seconds before I can get the turbine system to start. |
| 4 | Can I have it where I want it? | Yes, all my sets are functioning at the moment and feeding the electricity manufacturer's transformers as required | No – there are some parts of me (electrical bits) that cannot be maintained and just have to be replaced as and when appropriate |
| 5 | What quality is available? | Electricity at required voltage to pass on to the electricity manufacturer's transformers | Good –all staff that maintain me know what they are doing. Secondary signal system ensures that I am very likely to receive the signal when it is required |
| 6 | How much can I afford to give for it? | The maintenance budge for each generation set (and governor) is decided by the generation system management | The quicker the start-ups the more wear will occur. The more maintenance the turbine receives, the quicker I can ask it to respond (and the harder I can ask it to work) |
| 7 | How much is the minimum that I need? | Enough to supply the demands of the generation system managers | Signal – one. Maintenance – at least every X working hours – but risk does increase at this low level |
| 8 | Who can I get it from? – possible suppliers | Any turbine/governor system that is operational and can react to the demand | Upper echelons of the electricity manufacturing company |

The reverse usage case has the following successful scenario:

The **power station governor** is under pressure because the turbine system is trying to spin. The **power station governor** sounds a warning and asks the *generation system* whether it can please generate electricity according to its requirements. The *generation system* agrees

to take electricity from the power station governor according to its conditions. The *generation system* pays for the electricity in accordance with the power station governor's requirements. The *power station governor* gets the turbine system to generate the electricity in accordance with the *generation system*'s conditions.

Governor Interactions

The governor asks the *turbine* to spin the shaft in order to generate electricity in accordance with its requirements. The *turbine* agrees to spin the shaft for the governor according to its conditions. The governor agrees to the *turbine*'s conditions. The *turbine* spins the shaft according to the governor's requirements. The governor pays for the spinning of the shaft according to the *turbine*'s conditions.

| Primary actors | Interests |
|------------------------------------|--|
| <u>Governor (customer)</u> | Wants to receive maintenance in return for controlling the speed of the turbine |
| <i>Turbine (organisation)</i> | Wants to receive maintenance in return for spinning at the required speed and thus allowing the generator to produce electricity |
| Precondition | The <u>governor</u> is experiencing a demand from the generating system management to control the speed of the turbine |
| Success guarantee (post condition) | <u>Governor</u> has received a signal from the turbine system to show that it is spinning at the required speed |
| Shadow usage cases | |

| | Prompts | Governor Requirements | Turbine Requirements |
|---|--|---|--|
| 1 | What do I need from this transaction? | To ensure that the turbine spins at the speed requested by the generating system management | Feedback from the governor and maintenance |
| 2 | How much of it do I want (from this transaction)? | Signal that turbine is spinning at required speed | Enough to ensure that I can reliably spin at the required speed |
| 3 | When do I want it? | As required by my agreement with the generating system management | Maintenance every X working hours – feedback to let me know if I am spinning at the right speed |
| 4 | Where do I want it? | Signal through control system | Signal through control system – maintenance where required |
| 5 | How do I want it (quality)? | Electric or mechanical feedback | Clear signal through electrical or mechanical system. Maintenance by experienced professional |
| 6 | How much will I give for it (depends on values and perceived level of need)? | My full capacity to control the speed of the turbine (mechanical and or electrical) | Spin and required speed |
| 7 | Why do I need it (why do I value it)? | The generating system management is demanding it and I've agreed to its requirements | To ensure that I spin at the required speed to ensure that the shaft and rotor spin and that the amount of electricity required by the generating system (and electricity manufacturer) is generated |
| 8 | Who will I get it from? (linked to 6) – preferred supplier | The turbine control system (brakes, excitors etc) | The generation system management group and staff employed to maintain me |

| Prompts | | Governor Constraints | Turbine Constraints |
|---------|--|---|--|
| 1 | What is prompting me to carry out this transaction? | The generation management are demanding that I ensure that the turbine rotates at the correct speed to facilitate the production of electricity | This is the process I enact – I exist to spin the shaft |
| 2 | What is my capacity for using and storing the product? | IT is control situation, I have to keep monitoring it, but the turbine has some kinetic energy (and inertia) | I can operate within safe margins as long as I am maintained according to my requirements. I react to governor feedback signals within Y seconds. |
| 3 a | When is the earliest that I can get it? | I can get the turbine to full working speed within X minutes of request. I can slow it to a stop from Y rpm to standing in P seconds | I start to spin as soon as the water jets hit me, and I slow down within X seconds of the braking system being applied by the governor |
| 3 b | When is the latest I can get it? | I need to keep the turbine speed steady, thus I need to control it to within P rpm of the required speed, all the time | Fuzzy – but the longer apart the maintenance is the more likely I am to fail. It takes me R seconds to overcome inertia (before starting) and S seconds to slow down (to stop) |
| 4 | Can I have it where I want it? | If the turbine sub-processes are OK (e.g. there is enough water), then yes. | No – some bits of me can only get maintained during refurbishment as they are inaccessible, therefore a small risk must be taken (unknown) |
| 5 | What quality is available? | I can control the turbine to within R rpm of the required speed | Good –all staff that maintain me know what they are doing. |
| 6 | How much can I afford to give for it? | The maintenance budge for each turbine is decided by the generation system management | The quicker the start-ups the more wear will occur. The more maintenance I receive, the quicker I can respond. Also, I need water from the water supply system. |
| 7 | How much is the minimum that I need? | I need to control the turbine velocity to within X rpm within Z seconds of giving the signal | Signal – one. Maintenance – at least every X working hours – but risk does increase the lower the maintenance level |
| 8 | Who can I get it from? – possible suppliers | My electrical mechanical system and the turbine working together in a control feedback loop | Signal from the governor and maintenance from the generation management. |

The reverse usage case has the following successful scenario:

The **turbine** is under pressure because there is water pressure trying to spin it. The **turbine** sounds a warning and asks the *governor* whether it can please apply the brakes according to its requirements. The *governor* agrees to take control of the **turbine** speed according to its conditions. The *governor* pays for the resulting speed (that leads to the generator producing electricity) in accordance with the **turbine**'s requirements. The **turbine** gets the generator to generate the electricity in accordance with the *governor*'s conditions.

Turbine Interactions

The turbine asks the *wicket gates* to supply it with water in accordance with its requirements. The *wicket gates* agree to supply the turbine with water according to their conditions. The turbine agrees to the *wicket gates*’ conditions. The *wicket gates* supply the water according to the turbine’s requirements. The turbine pays for the water according to the *wicket gates*’ conditions.

| Primary actors | Interests |
|------------------------------------|---|
| <u>Turbine (customer)</u> | Wants to receive water in order to be able to spin as fast as the governor is demanding |
| <i>Wicket gates (organisation)</i> | Want to be positioned in such a manner that allows them to meet the turbine’s demand for water pressure – and to receive maintenance in return for doing this |
| Precondition | The <u>turbine</u> is experiencing a demand from the governor to spin the shaft faster |
| Success guarantee (post condition) | <u>Turbine</u> has received water from the wicket gates system and is spinning as required by the governor |
| Shadow usage cases | |

| | Prompts | Turbine Requirements | Wicket gates Requirements |
|---|--|---|--|
| 1 | What do I need from this transaction? | Water | Control system, feedback from turbine and maintenance |
| 2 | How much of it do I want (from this transaction)? | X litres/second | Enough feedback, control and maintenance to ensure that I meet the turbine demand |
| 3 | When do I want it? | As required by my agreement with the generator to spin at the required speed | Maintenance every X working hours – feedback to let me know if I positioned correctly |
| 4 | Where do I want it? | On my blades | Signal through control system – maintenance where required |
| 5 | How do I want it (quality)? | At a specific angle to the blade surface and a pressure of Q N/mm ² | Clear signal through electrical or mechanical system. Maintenance by experienced professional |
| 6 | How much will I give for it (depends on values and perceived level of need)? | I give directly to the shaft (see other interaction) but indirect payment will be given to the wicket gates | As much water as can pass through me (depends on level in penstock) |
| 7 | Why do I need it (why do I value it)? | Because the governor requires me to speed up so that I turn the shaft faster | To ensure that I am correctly positioned and strong enough to withstand the water pressure from the penstock without failing |
| 8 | Who will I get it from? (linked to 6) – preferred supplier | The penstock, via the wicket gates | The generation system management group and staff employed to maintain me and the wicket gate control system |

| Prompts | | Turbine Constraints | Wicket gates Constraints |
|---------|--|---|---|
| 1 | What is prompting me to carry out this transaction? | The generator is demanding that I spin faster so that the shaft spins shaft | This is the process I enact – I exist to direct water onto the turbine |
| 2 | What is my capacity for using and storing the product? | I can process q litres of water per second, which causes me to spin at my top speed of F rpm | If I am closed I can assist the penstock in storing water, but I can't store it myself. My maximum capacity for passing fluid is X litres/second |
| 3 a | When is the earliest that I can get it? | Once the wicket gates are passing q litres/second and it is hitting my blades | I start to spin as soon as the water jets hit me, and I slow down within X seconds of the braking system being applied by the turbine |
| 3 b | When is the latest I can get it? | Just in time to enable me to spin at the speed required by the governor, in accordance with my contract with the governor | Fuzzy – but the longer apart the maintenance is the more likely I am to fail. I need to receive the signal to change position x seconds before I need to be at that position. |
| 4 | Can I have it where I want it? | If the wicket gates function and there is sufficient water in the penstock, yes | No – some bits of me can only get maintained during refurbishment as they are inaccessible, therefore a small risk must be taken (unknown) |
| 5 | What quality is available? | The water is clean and clear of debris and the wicket gates ensure the correct quality of jet | The staff maintain me well. The water is clean and clear of debris, so that I don't get jammed |
| 6 | How much can I afford to give for it? | The maintenance budge for the wicket gates is decided by the generation system management | I can pass up to x litres per second as long as the penstock can supply it to me |
| 7 | How much is the minimum that I need? | The equivalent of q psi. | Signal – one. Maintenance – at least every X working hours – but risk does increase the lower the maintenance level |
| 8 | Who can I get it from? – possible suppliers | From the penstock directly or through the wicket gates | Signal from the wicket gate control system (from the turbine) maintenance from the generation management. |

The reverse usage case has the following successful scenario:

The wicket gates are under pressure because there is water pressure trying push them open. The wicket gates are forced open and demand that the *turbines* spin according to their requirements. The *turbine* agrees to pass the water from the wicket gates according to its conditions. The *turbine* demands a payment from the generation management system to repair and strengthen the wicket gates and prevent this situation of uncontrolled spin reoccurring.

Wicket Gate Interactions

The wicket gates ask the *penstock* to supply them with water in accordance with their requirements. The *penstock* agrees to supply the wicket gate with water according to its conditions. The wicket gate agrees to the *penstock*'s conditions. The *penstock* supplies the water according to the wicket gates' requirements. The wicket gate reacts to the provision of the water in accordance with the *penstock*'s conditions.

| Primary actors | Interests |
|------------------------------------|---|
| <u>Wicket gates (customer)</u> | Wants to receive water according to its requirements |
| <i>Penstock (organisation)</i> | Wants to reduce the water pressure on its walls |
| Precondition | The <u>wicket gates</u> identify a need (from the turbine and wicket gate control system) for water |
| Success guarantee (post condition) | <u>Wicket gates</u> have received water according to their requirements and <i>penstock</i> has received 'payment' from the wicket gates. |
| Shadow usage cases | <u>Penstock</u> – <i>Pressure alarm system</i> <u>Wicket gates</u> – <i>turbine governor</i> . |

| | Prompts | Wicket Gate Requirements | Penstock Requirements |
|---|--|--|---|
| 1 | What do I need from this transaction? | Water | Reduced pressure on the penstock walls |
| 2 | How much of it do I want (from this transaction)? | As much as the turbine tells me it needs to produce the electricity required | Reduction to less than maximum safety levels |
| 3 | When do I want it? | On demand | On demand |
| 4 | Where do I want it? | Entering through the vanes on the gate | All over – by water escaping from the turbine end of the penstock |
| 5 | How do I want it (quality)? | Without trash in it and not too fast so it won't cause cavitation | On demand, in time so that no back-surge or unsafe pressure occurs |
| 6 | How much will I give for it (depends on values and perceived level of need)? | Corresponding release in water pressure to the penstock | Volume of water that can pass through penstock at the time given wicket gate opening |
| 7 | Why do I need it (why do I value it)? | The turbine is demanding it | Otherwise I will become unsafe and may crack – and the intake system refuses to accept a back-surge |
| 8 | Who will I get it from? (linked to 6) – preferred supplier | The penstock | The wicket gate under normal operation or the intake system in an emergency |

| Prompts | | Wicket Gate Constraints | Penstock Constraints |
|---------|--|--|---|
| 1 | What is prompting me to carry out this transaction? | The turbine system is demanding a certain pressure of water at a certain time to make it spin | My walls are under pressure and approaching maximum safe operating pressure |
| 2 | What is my capacity for using and storing the product? | I can channel up to X metres cubed of water per second (if the turbine system lets me) | I can safely store up to X metres cubed of water at up to Y metres cubed per square metre pressure |
| 3 a | When is the earliest that I can get it? | It depends how much water is in the penstock now, the position of the intake gate and the level of water in the reservoir | It depends how quickly the system senses my predicament and how quickly the turbine can be started (if stopped) or speeded up (if spinning) |
| 3 b | When is the latest I can get it? | Just before the turbine starts to reduce velocity (unless that is the plan, in which case it can wait til more water is demanded by the turbine) | Just before my maximum safe operating pressure is reached |
| 4 | Can I have it where I want it? | Yes, along as the penstock system can provide it | Yes, along as the wicket gate and turbine system (or intake tower in emergency) is operational |
| 5 | What quality is available? | The water is clean so long as the trash rack is doing its job. | The wicket gate can take the water so long as it is operational and the turbine system allows it to operate |
| 6 | How much can I afford to give for it? | My maximum capacity for passing water is X metres cubed per second | My maximum capacity for passing water is X metres cubed per second |
| 7 | How much is the minimum that I need? | As much as the turbine demands (but if I go below Q metres per second it causes problems downstream) | Enough to maintain my water pressure below the safe operating maximum |
| 8 | Who can I get it from? – possible suppliers | The penstock is the only supplier of water open to me | The wicket gate or the intake system and reservoir |

The reverse usage case has the following successful scenario:

The **penstock** wants get rid of water according to its requirements. The **penstock** asks the **wicket gates** to take the water. The **wicket gates** agree to take water from the **penstock** according to their conditions. The **wicket gates** take the water in accordance with the **penstock**'s requirements. The **penstock** supplies the water in accordance with the **wicket gates**' conditions.

The following table summaries the above:

| Table C.2: Identifying Actors and Goals from External Events | | | |
|--|---------------------|--------------------------------|---|
| From Actor | External Event | To Actor | Goal |
| Customer | Flicks the switch | Asking the Switch | Turn on the light |
| The Switch | Demands Electricity | From the Domestic Power Supply | To power the light |
| The domestic power supply (Distribution Tranformer) | Demands Electricity | From the Electricity Supplier | To meet the domestic electricity demand |
| The Electricity Supplier | Demands Electricity | From the Electricity Generator | To supply the domestic electricity power supply |
| The Electricity Generator | Demands Electricity | From the Generator Machine | To supply the Electricity Supplier with Electricity |
| The Generator Machine | Demands Water | From the Penstock System | To enable the turbine to spin the rotor which results in electricity generation |
| The Penstock System | Demands Water | From the Reservoir System | To supply the Generator Machine with water |
| The Reservoir System | Demands Water | From the Environment | To supply the penstock system with water |

Appendix D

The Performance Improvement Cycle

D.1 Introduction

The Performance Improvement Cycle (PIC) has been developed during months of work at FaberMaunsell. As such, it is in addition to the original research described in this thesis. However, the author has lead the development of the Cycle and has been the Project Manager of attempts to market it to potential clients. The approach is receiving a lot of interest in the water and highway sectors in particular, although this reflects the marketing priorities of the company. It is a simple and generic methodology that could be applied to any sector, and the Asset Management department, and the Infrastructure and Environment Division's top management see it becoming the catalyst for expansion into a number of key markets.

This appendix aims to explain the key principles of the PIC and to demonstrate the way in which it supports broader Asset Management concepts, thus extending the work undertaken in the original research described in this thesis.

D.2 The Performance Improvement Cycle

The PIC is exactly what the name implies, a cycle with the goal of helping an organisation improve performance. However, the exact way in which it could or should be deployed is not clear. Without doubt, the correct depth, breadth and detail of the application will depend on the needs of the client organisation. This is why the PIC is generally introduced after a presentation to the client about the general principles of Asset Management. Combined with the use of the Solutions Focus, the PIC has been successfully used in a half-day workshop with a local authority, which resulted in many needs being pointed up.

The PIC comprises 5 stages, each of which can be repeated as often as required. The stages are:

1. *Process modelling*: Identifying what the client does now, through the construction of a hierarchical process model.
2. *PI analysis*: Checking existing PIs are logical and in line with the organisational strategy. Linking valid PIs to process model to identify gaps in measuring system.

- 3. *Risk weighting*: Determining the relative importance of the processes in the model to ascertain which areas are key priorities for improvement or increased monitoring.
- 4. *Gap Analysis*: Determining how to rectify the gaps identified thus far, including improving processes, developing new PIs and carrying out *scenario testing*.
- 5. *Continual Improvement*: Checking the change in performance (or reduction in uncertainty) resulting from the first pass of the PIC and continuing the process in the longer-term.

D.3 Application to Asset Management

According to the International Infrastructure Management Manual (IIMM), there are two levels of Asset Management, “Basic” and “Advanced”.

Basic Asset Management “relies primarily on the use of an asset register, maintenance management systems, job/resource management, inventory control, condition assessment and defined levels of service in order to establish alternative treatment options and long-term cashflow predictions. Predictions are usually established on the basis of financial return gained by carrying out the work (rather than risk analysis and optimised decision-making)”.

Advanced Asset Management builds on Basic Asset Management and “employs predictive modelling, risk management and optimised decision-making techniques to establish asset lifecycle treatment options and related long term cashflow predictions”.

The following table demonstrates how the key stages of the PIC relate to areas of Asset Management.

| | | PIC Stage |
|------------------------|---|---|
| Basic Asset Management | Asset Register | |
| | Maintenance Management | |
| | Job/resource Management | 1: Process-modelling: Establishing links between various jobs |
| | Inventory Control | |
| | Condition Assessment | 2: PI Analysis: Linking condition to performance/ service |
| | Levels of Service definition | |
| | Establish alternative treatment options | |

| | | |
|---------------------------|--------------------------------------|--|
| Advanced Asset Management | Predictive modelling | 3/4: Identifying the effect of new systems and changes in PI status |
| | Risk Management | 3/4: Weighing up importance of various processes, scenario testing, examining uncertainty |
| | Optimised decision-making techniques | All: Facilitating expert debate, recording opinions, making decision with uncertainty, identify need for DSS |
| | Asset lifecycle treatment options | All: Scenario testing, and “what if” analysis – identify needs for deterioration models |

Table D1: Relationship between PIC and AM

Looking specifically at Infrastructure Asset Management, the IIMM (section 1.1.3) lists a number of key elements for the discipline. The idea is to provide services in the most cost-effective manner, and to demonstrate this to customers, investors and other stakeholders. The list below demonstrates which of these elements can supported by the PIC approach.

| | |
|---|-----|
| Taking a lifecycle approach | ✓✓ |
| Developing cost-effective management strategies for the long-term | ✓✓ |
| Providing a defined level of service and monitoring performance | ✓✓✓ |
| Managing risks associated with asset failures | ✓✓ |
| Sustainable use of physical resources | ✓ |
| Continuous improvement in asset management practices | ✓✓✓ |

(✓✓✓ = core benefit of PIC, ✓✓ = applicable benefit of PIC, ✓ = indirect benefits using PIC)

It is clear from the above discussion that there are many ways in which the PIC can support an Asset Management Framework. The key AM benefits of the methodology are highlighted in the following table. These benefits are taken from the IIMM and the extent to which they are supported by the PIC is identified in the following table.

Core Benefits of AM**How this is supported by the PIC***Improved stewardship and accountability by:*

- Demonstrating to owners, customers and stakeholders that services are being delivered efficiently and effectively
- Providing the basis for evaluating and balancing service/price/quality trade-offs
- Improving accountability for use of resources through published performance and financial measures
- Providing the ability to benchmark results against similar organisations
- Populated process model visually and clearly demonstrates the current situation, original situation, and predicted change from scenario
- Different aspects of performance can be weighted separately and fed into the model
- Framework for visualising all performance indicators, linking to process and developing a PI cascade
- Benchmarking own progress – including reductions in uncertainty

Improved communication and relationships with service users by:

- Improved understanding of service requirements and options
- Formal consultation/agreement with users on the service levels
- More holistic approach to asset management within the organisation through multi-disciplinary management teams
- Improved customer satisfaction and organisation image
- Stimulating discussion and finding agreement of service requirements and options
- Facilitating consultation through a visual, populated, process model
- Identifying cross-discipline linkages through creation of the process model. Identifying input/output dependencies for resources and information
- Demonstrating that the organisation employs modern techniques.

Improved risk management by:

- Assessing probability and consequences of asset failure
- Addressing continuity of service
- Addressing the inter-relationships between different networks (the chain is only as good as its weakest link) and risk management strategies
- Influencing decisions on non-asset solutions through demand management
- Identifying areas of poor performance and of high uncertainty
- Providing a robust foundation for change
- Pointing up key processes where failure cannot be tolerated so that resources (both of repair and monitoring) can be allocated more effectively
- Demonstrating the interconnectivity between asset and non-asset systems

Improved financial efficiency by:

- Improved decision-making based on costs of alternatives
- Justification for forward works programmes and funding requirements
- Recognition of all costs of owning/operating assets over the lifecycle of the assets
- Improved decision making from viewing how alternatives affect performance and uncertainty
- Framework for recording decisions and defending forward works / funding
- Recognition of areas where, due to uncertain performance, lifecycle costs are very difficult to calculate / may not be reliable.

Strategic Planning

The PIC can be used to support strategic planning. In order to build the process model it is essential to first identify the “top box” – the mission or vision of the organisation. In many cases this is not clear and it may be necessary to begin by developing a mission (if none exists) or synthesising a number of statements into one through the use of workshop sessions and consultation.

During this initial stage of the PIC it is also essential to identify all the demands being placed on the organisation. This is because each of these demands must be “translated” into a response by the organisation. These “demand” diagrams can reduce a complicated situation to a manageable demand model which may include both internal (e.g. CEO, board and other corporate demands) or external. The latter may be a legislative demand, which must be met (e.g. safety, environmental restrictions) or some other demand, such as financial demand from stakeholders, or a need to have “shine” – to be trusted and respected by the local

community and other interested parties. One of the strengths of the PIC is that different aspects of performance (e.g. cost, safety, environment) can be measured for each process, and weighted according not only to their general importance (e.g. safety is twice as important as cost) but given a different weighting for each process, if desired.

Once a process model has been populated with the existing evidence for performance it becomes possible to test a number of scenarios to determine which best achieves the strategic goals of the mission statement. The model itself then becomes an unambiguous, clear record of the strategic direction, goals, targets and desired outcomes that were the priority at the time the model was developed. This then feeds into the tactical level of planning as well as providing a benchmark for future comparison.

In summary, the PIC is ideal for understanding how external and internal demands affect all the processes within the organisation, and for communicating these demands (and resulting actions) to stakeholders.

Tactical Planning

The tactical planning is the ‘middle level’ of the organisations. It translates the broad strategic goals and plans into specific objectives for different levels of the organisation. The achievement of these tactical level goals is driven through the various plans at the tactical level. These vary from organisation to organisation but generally include financial, marketing, customer service, health and safety, human resources and asset management plans.

The PIC can play an important role in ensuring that these tactical plans do drive the organisation in the direction of the strategy.

Operational Planning

The PIC has been proposed as a key part of the methodology for improving data quality at Network Rail. This application is appropriate as the approach can be used at even a micro-scale to demonstrate how uncertainty and incompleteness in the data can lead to poor decision-making.

In the longer term, it will be possible to link operational decisions such as “should we collect this data, and if so, how often and with what method?” through the tactical planning and

demonstrate the impact on the “goal”; the delivery of customer service and stakeholder satisfaction.

D.4 Recent Applications and Results

The PIC has been successfully applied in a number of case studies and small projects. It is hoped that this area of work will continue to develop once some of the “take-up” and assimilation issues described in Chapter 10 of the thesis have been resolved.

D.5 Conclusion

The PIC is a much simpler approach to explain (being only five steps) than the fourteen to forty points of the established Quality Management Masters (Bicheno, 2002). Through the development of the PIC the author and her colleagues at FaberMaunsell have taken the results of this thesis and developed them into a marketable product. This demonstration of industrial application of the research is one of the key reasons why the CMAM research received such praise in the post-project review.